X RAYS:

THEIR ORIGIN, DOSAGE, AND PRACTICAL APPLICATION

FOURTH EDITION,

JULY, 1932.

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BY

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PREFACE TO FIRST EDITION

This book is the successor to "Electro Medical Instruments and their Management," which was published for the first time in 1892

Since that time, the advent of X rays and the development both of that art and science and of electro medicine in general have made it necessary to divide the original publication in two, of which the one deals with X rays alone and the other with general electro medical work.

In this, the X-ray section, I have endeavoured to explain the physical laws, the electrical and practical part, and especially the dosage, and I trust that it will be a help to many beginners and medical students

I wish especially to thank my father, Mr K Schall, for the great amount of help and advice which he has given me in the writing of this book

W E SCHALL, B Sc Lond.

London, 1923

PREFACE TO FOURTH EDITION

When the first and second editions of this book had appeared, it was thought that a new edition would be unnecessary for several years, but the rapid development in the current carrying capacity of the hot cathode X ray tube and valve about that time revolutionized the design of high tension generators, and very considerably modified radiographic technique A large new edition was, therefore, published in 1928, but this also has now been exhausted

I have frequently been assured that this book fills a gap, and have therefore, endeavoured to bring its contents up to date

The spark coil and its accessories are still described, since an understanding of their action is useful in appreciating the action of the modern closed core transformer The chapters on tubes, dosage, X ray physics, and particularly on transformer units, have been considerably enlarged

W E SCHALL, B Sc Lond

London,
July, 1932

CONTENTS

X RAYS:

THEIR ORIGIN, DOSAGE, AND PRACTICAL APPLICATION

CHAPTER I

THE ORIGIN AND PROPERTIES OF X RAYS

HISTORICAL

X RAYS were discovered by Professor Rontgen in Wurzburg in December, 1895, whilst he was experimenting on the passage of electricity through rarefied gases

Davy, in 1822 and Pflucker, in 1858, had noticed that when two metal electrodes are sealed into the ends of a glass tube and connected to a source of electricity outside, which is capable of supplying high voltage, the sparks which are produced between the electrodes undergo a series of changes if the gas pressure in the tube is reduced

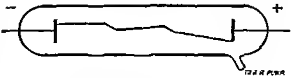


Fig 1

When the air in such a tube is removed till the pressure inside falls to about *one hundredth* part of an atmosphere, so that the mercury column of a barometer would have dropped from 760 mm to 8 mm, the sharp edged crackling sparks (Fig 1) change to a furry noiseless caterpillar like band (Fig 2)

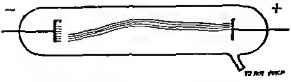


Fig 2

At a pressure of 1 mm of mercury the diameter of the discharge has increased, till the whole tube appears filled with light The resistance to the passage of electricity is much less, and a spark which in air, would only just bridge a gap of 5 cm can discharge through a tube 100 cm long when the air pressure is thus reduced This phenomenon was used by Geissler in making tubes of various designs which would light up when

excited electrically, and were known as Geissler tubes. To-day the same phenomenon is employed in the so-called neon tubes, which give a bright red light for advertising purposes.

When the pressure is still further reduced a dark patch known as the Faraday dark space, surrounds the negative pole or cathode (Fig. 3). At a yet lower pressure the luminosity of the tube breaks up into a number of bands known as striæ, whilst a second dark space appears round the cathode. It is known as the Crookes' dark space (Fig. 4).

Fig. 3.

When the pressure has fallen to 0.001 mm. or thereabouts the dark space round the cathode fills the whole tube to the exclusion of all luminosity, but now the glass walls of the tube light up brightly with a fluorescence the colour of which depends on the materials which went to make the glass. Soda glass produces the apple green which is apparent in some X-ray tubes, whereas lead glass shows a blue colour.

Fig. 4.

Hittorf, in 1869, discovered that the dark space within the tube under these conditions is not merely an emptiness, but that there is evidence of rays which appear to come from the negative pole or cathode and are therefore called Cathode Rays. Little attention was paid to them till Sir William Crookes began his interesting experiments in 1879. The cathode rays are a stream of units of negative electricity to which the name *electrons* has been given. The electron is so small that its mass is only the eighteen hundredth part of the mass of an atom of hydrogen. Crookes showed by means of a tube with a cross which could be raised or lowered (Fig. 5) that the electrons of which the cathode stream consists leave the cathode at right angles to its surface and fly in straight lines. When the cross is raised into the path of the cathode stream it casts a black shadow on the fluorescent wall of the tube—thus showing at the same time that the fluorescence is due to the atoms of glass being struck by flying electrons.

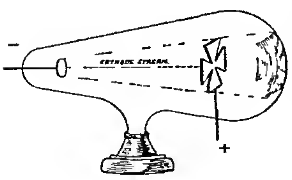


Fig. 5

The speed of these electrons varies from one-third to four fifths of that of light, and is directly proportional to the electric tension which is applied to the ends of the

tube When the cathode is given the shape of a concave mirror the stream of electrons converges to the focus Furthermore, it is deflected from its path by a magnet The cathode stream does not pass through matter except to a very slight degree On striking an object like the glass wall of the tube, or the cross in Fig 5, etc , the electrons are stopped and their energy is converted More than 99 per cent of it changes to heat which explains why the glass wall opposite such a cathode rapidly becomes too hot to touch and may even melt and collapse The remainder (less than 1 per cent) is converted into

X RAYS

While experimenting with such tubes, Rontgen found that when the electrons of the cathode stream strike matter such as the glass wall of the tube, or better still, a metal of high atomic weight placed in their path inside the tube, the point of impact becomes the source of a new radiation These rays, though invisible to our eyes, excited certain substances such as barium platino cyanide and calcium tungstate to fluorescence, and exerted the same effect on photographic emulsions as ordinary light They penetrated not only the glass walls of the tube but other substances which are opaque to ordinary light, like wood, ebonite, flesh, and, to a smaller extent, even metals Röntgen called them X rays

The "transparency" of various materials was found to depend on their atomic properties, their thickness and their density—and to a large extent on the penetrating power of the rays Aluminium, for instance, is about as transparent as glass but ten times more opaque than water, whereas lead is almost entirely opaque Flesh is more transparent than bones, the lungs filled with air are more transparent than the heart filled with blood

When X rays penetrate matter, a part of them passes right through and the remainder, the amount of which depends on the "transparency" of the matter, is "absorbed" The part which passes through is used by doctors to excite a fluorescent screen or to act on a photographic emulsion for diagnostic purposes And the part which is absorbed surrenders its energy, which is converted into chemical, electrical, thermal, and biological effects and again serves the doctor as a therapeutic agent

The degree of all these various effects depends on the quality and the quantity of the X rays It is evident that anyone who wishes to employ X rays with success and without risk to his patient should study both their nature and properties and the methods of producing controlling and measuring them

CHAPTER II

THE X-RAY TUBE

The apparatus wherewith we produce X rays consists of two important and distinct parts (1) The X ray tube wherein the high tension electrical energy is converted into X rays, and (2) The transforming unit which converts the electrical current from our supply mains to high tension current of a form suitable to be passed through the X ray tube

The original type of X ray tube was as we have seen, a glass cylinder or bulb into whose ends were sealed two electrodes Air was pumped out until only a small residue remained and then the electrical current which left the negative electrode as a stream of electrons (the cathode rays) produced X rays by bombarding the glass wall opposite, or some metallic object placed in its path Till recently this arrangement was simply called an X ray tube, but the coming of a special type of such tube in which the negative pole or cathode is heated has given rise to the terms "gas tube" and "hot cathode tube" Abroad, the gas tube is generally known as the "ion tube" and the hot cathode tube as the "electron tube"

GAS TUBES

The gas tube has practically gone out of use It was employed with spark coils in the early days of X ray work but the hot cathode tube which is so much more easily controlled, has superseded it A study of it is, however, both interesting and instructive

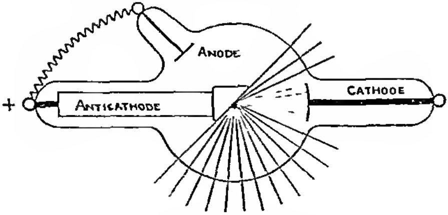


Fig 6

The classical form of an X ray tube is shown in Fig 6, and consists of a spherical glass globe from which project two necks at opposite ends of a diameter Into one of these is fixed an aluminium stem carrying a concave disc, also of aluminium, so placed

that it is flush with the circumference of the glass globe This is the cathode or negative electrode Into the other neck is fixed a stem carrying a block of copper faced with tungsten or platinum This is the positive pole or anticathode, and it is placed at the centre of the glass bulb The radius of the concavity of the cathode is such that its centre or focus lies on the surface of the anticathode, and the face of the anticathode makes an angle of 45° with the axis of the cathode neck Most gas tubes have two further glass necks fixed somewhere on the bulb "behind" the anticathode One of these contains yet another electrode known as the anode, which serves for manufacturing purposes only, and of the other, which is used for regulating the vacuum and is called the regenerating device, we will speak later In Fig 6 the full lines denote X rays and the dotted lines cathode rays

If we connect the ends of such a tube to a source of unidirectional high tension current, we will find that at a certain voltage, depending on the degree of evacuation of the tube, a current will pass, giving rise to X rays

Even to day, the actual process inside the gas tube is a little obscure, but the following explanation is probably reasonably near the truth As the voltage on the electrodes is increased, a point is reached where a slight discharge of electrons from cathode to anticathode begins These electrons collide with the atoms of residual gas in the tube and ionize them That is to say that, by collision, they detach from the electrically neutral atoms some of their constituent electrons (see also p 54) leaving positively charged ions and free electrons These free electrons when they are near the cathode, are violently repelled from it and flung towards the anticathode The positive ions, on the other hand, are attracted towards the cathode, which they bombard, but at much less velocity than that with which the electrons fly away When the ion strikes the cathode it may detach electrons from the metallic atoms there and again become a neutral atom, or it may even knock complete metallic atoms out of the cathode, thereby causing the disintegration of the latter The electrons which are thus detached from the cathode are replaced by the electric current which flows to it from the high tension apparatus outside the tube The value of the voltage at which this state of affairs sets in is called the ionization potential The ionization potential is the higher the less residual gas is present, because less atoms evidently offer less chance of ionization by collision to the few electrons which leave the cathode and start the ionization and until ionization sets in i e, while the only current that can flow consists of the few electrons which happen from other causes to be present in the gas, the tube acts as a high resistance

As the voltage is raised above the ionization potential the amount of ionization is increased, that is to say, more electrons become available for the cathode stream and therefore the current rises The reason is that increased voltage means increased speed of the flying electrons, and this in turn means both more violent and more numerous collisions—resulting in yet more electrons

We therefore get a considerable interlinking of phenomena in the gas tube The degree of evacuation of the tube determines the voltage at which the tube commences to work Both the degree of evacuation and the voltage together determine the amount of ionization, i e, the current

When the electron reaches the anticathode it is suddenly stopped and its energy of motion (kinetic energy) is converted into X rays and heat. Less than 1 per cent is converted into X rays, whilst the rest is absorbed in raising the temperature of the anticathode The faster the electron has been flying, the shorter is the wave length of the X rays which are produced, i e, the more penetrating or harder is the radiation, and the slower the electron was flying, the longer is the wave length (less penetrating or softer rays)

A tube with much residual gas (low vacuum, soft) will commence to work at a comparatively low voltage and will produce long wave, slightly penetrating X rays, as a result of slow moving cathode stream electrons A tube with little residual gas (high vacuum, hard) will require high voltages to start it, and will give off short wave, highly penetrating X rays because its cathode stream has great velocity At any given voltage, the soft tube will pass more current than the hard tube

One further phenomenon of the gas tube remains to be described Some of the electrons of the cathode stream are not brought to rest in the anticathode but appear to be reflected from it in all directions They radiate outwards and strike the glass wall of the tube all over the hemisphere situated in front of the anticathode. They cause the glass to fluoresce with a characteristic green colour and set up X rays at the spot where they hit the glass They probably find a home after the impact in positive gas ions which they thereby convert into neutral gas atoms They warm up the glass wall, but the heat so generated is small and not dangerous to the tube, because the electrons in question are moving comparatively slowly after having been reflected, and are spread over half the X-ray bulb

The Design of Gas Tubes—Gas tubes all resemble Fig 6 in the most important features, but a considerable variety of design in detail has arisen with a view to satisfying the one or other need The cathode is always made of aluminium, because it is found that metals of low atomic weight disintegrate least when bombarded by the positive gas ions

The metal of the anticathode must be of high atomic weight and specific gravity in order that it may arrest the cathode stream suddenly and so produce X rays Moreover it must have a high melting point so that it shall not suffer from the intense heat at the focus of the electron stream Platinum used to be employed for the purpose, but lately tungsten has come into universal use, because although its atomic weight is less, its melting point is higher, and with the increased output of modern high tension generators this became the more important factor

The heat which is produced in the anticathode is removed in a variety of ways In one case the tungsten disc is soldered on to a massive block of copper, which is a good conductor of heat and whose specific heat is so high that it can absorb much before its temperature rises In other tubes the tungsten disc is backed by a comparatively small block of copper which is connected by a copper rod to a fin radiator outside the tube

In yet another type the tungsten disc forms the bottom of a cylindrical vessel which takes the place of the anticathode neck and is filled with water The heat generated by the cathode rays brings the water to boiling point and is carried away in converting water at 100° C into steam at 100° C, the anticathode thereby remaining

at this temperature The advantage of this will be seen when we remember that whilst only 80 calories are employed in raising 1 grm of water from 20° C to 100° C, 539 calories are necessary to convert that gramme of water at 100° C into steam at 100° C The boiling water anticathode thus ensures a much steadier temperature with more constant air pressure conditions inside the tube

The heat question becomes more difficult if the anticathode is exactly in the focus of the cathode The cathode rays then converge in a sharp point, and the heat may become so great there that even tungsten will melt and a little cavity be formed in the surface of the anticathode But if it is placed a little inside the focus, so that the cathode rays are spread over a circle of a few mm diameter, the heat is more evenly distributed and the surface remains smooth For therapeutic purposes it is not necessary to have a sharp focus, and a blunt one of about 5 mm diameter is therefore invariably preferred, but for tubes intended for diagnostic purposes a fairly sharp focus is necessary It should not exceed 1 mm in diameter, otherwise the outlines of the shadows will become blurred For some purposes, for instance for examining fractures, or for finding foreign bodies like bullets, this would not matter much, but finer details disappear if the outlines are not sharp (see p 129)

In tubes which are intended for prolonged therapy even the cathode becomes heated owing to the continued bombardment by positive gas ions Cathodes in such tubes are often fitted with fin radiators as well

It adds to the smooth running of the tube if we connect the anticathode and the anode terminals by a spiral of wire

Changes taking place in the Gas Tubes—It has already been mentioned that the quality of the rays, i e, the penetrating power, depends partly on the degree of evacuation This does not remain constant The currents discharging through the tubes produce changes which influence and vary the gas pressure If the current used is strong enough to heat the anticathode considerably, gases which are embedded in the pores of the metal become liberated and increase the quantity of gas in the tube, thus making the latter softer If the anticathode consists only of a thin disc of metal, as in water cooled tubes, or if the gases embedded normally in metals have been purposely expelled by making the anticathodes incandescent for some time during the process of evacuation there is not much risk that the tubes will become softer, but *new* tubes containing much metal which is still full of the normal amount of gases contained in metals have a great tendency to become softer, and with such tubes prolonged exposures, or short exposures with very strong currents, should be avoided If serious mistakes are made in this respect, the tubes may become so soft that they show a purple colour and are useless Such tubes have to be re-exhausted before they can be used again

After some exposures with moderate currents, the tubes will gradually become fit to stand stronger currents and longer exposures They can be "seasoned" to stand strong currents by connecting them repeatedly at intervals for a few minutes with a moderate current, which must not be so strong as to make the tube softer With some patience tubes can thus be trained to stand currents of 20 M A for over thirty seconds at a stretch without suffering harm

If the anticathode has been raised to a high temperature during or before the

process of evacuation, the tubes have no tendency to become softer even with fairly strong currents

Whilst the generation of heat softens a gas tube, another process goes on simultaneously which tends to harden it Some of the molecules of residual gas are tied to the glass walls of the tube or to metal parts within the tube by the electrical forces which are at work, and their disappearance increases the vacuum, thereby raising the resistance of the tube and making the X rays harder

This process is a very slow one with well-constructed tubes and electrical apparatus, but finally all tubes are bound to become too hard to be of any use Very weak currents which do not warm the anticathode perceptibly tend to make the tubes hard prematurely Such weak currents are not at all an economy, as many imagine, and should be avoided

These changes become more prominent when the diameter, i e, the cubic capacity, of a tube is small, it is therefore an advantage to use tubes with bulbs of fairly large diameter, an 8 in bulb has a cubic capacity four times as great as a 5 in bulb Tubes with bulbs larger than 8 in have been tried, but have not proved to be a success, because the protecting boxes enclosing them become unwieldy and too heavy

Normal Current—The vacuum will remain constant if the quantity of gases which is liberated is as great as the quantity which is being used up i e, if the tube is worked with its "normal" current. A milliammeter is most convenient to find out whether a tube has its correct "load" If the index of the milliammeter has a tendency to fall, the tube is growing harder, the current used is too weak and should be increased, if the milliammeter has a tendency to rise, the current is too strong for the present condition of the tube, it is becoming softer and the current should be reduced If these indications of the milliammeter are ignored the vacuum will change and failures owing to wrong penetration and exposure will be frequent, and the lifetime of the tubes may be shortened The normal current which each particular tube will stand should be known, and it can be written on a piece of stamp paper pasted on the neck of the tube The latitude in the normal current and the constancy of the tubes is much greater now than it was in the early years of X ray work

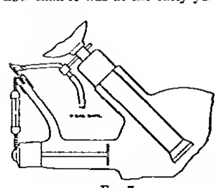


Fig 7

Regeneration of the Tubes—All gas X ray tubes are provided with some arrangement which allows the penetrating power to be lowered This can be done in various ways

First, the temperature of the anticathode can be raised slightly by forcing a strong current through the tubes for a short time

Secondly, many tubes have a small palladium tube projecting through the neck (Fig 7) This metal has the peculiarity that it allows hydrogen to pass through while it is incandescent, a process which is called osmosis The palladium tubes are heated with a small spirit or gas flame, but care must be taken not to overdo it The flame can also be ignited from a distance, or can even be lit automatically

when the tube becomes too hard In such cases the burner is placed below the palladium tube, and as soon as the current falls below the correct value, gas is allowed to flow through the burner, and is ignited by small sparks which discharge continually between the burner and the palladium tube The tube becomes softer, and as soon as the current through it has again reached the right value the gas tap is closed

Other tubes have a small cylinder attached to the bulb (Fig 8) containing some suitable chemicals which liberate gases when heated Two thin wire rods are attached to the terminals of this cylinder, and can be lowered so that they come near the terminals of the cathode and anticathode, when the distance is short enough, the current prefers to discharge

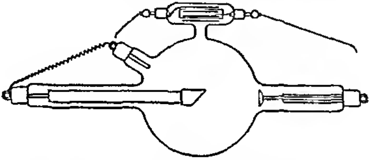


Fig 8

through this cylinder, because the resistance of this path is smaller than that of the much longer gap between cathode and anticathode The heat produced by the current liberates some gases occluded in the chemicals The rods can also be left so that the distance between their ends and the terminals of the tube is about half the length of the equivalent spark As soon as the tube begins to grow harder, sparks discharge between the tube neck and these rods until the vacuum has been lowered a trifle

To make the tubes harder, a weak current can be passed through them for some 20 or 30 minutes If this is not sufficient, repeat it after a rest of an hour or more The process is sure to succeed, but tubes which are much too soft of course require greater perseverance than those in which only a little hardening is wanted Tubes become harder quickly if the current is allowed to discharge in the wrong direction, but this must be avoided for two reasons First, the cathode rays which now start from what normally is the anticathode will strike the glass wall opposite and rapidly raise its temperature so high that it melts, thereby destroying the tube Secondly, if the current is too small to have this destructive effect it will, at least, disintegrate the anticathode as mentioned above and cause a metallic deposit on the tube wall which will seriously absorb X rays

Treatment of the Gas Tubes —The tubes should be free from dust and damp, otherwise sparks may discharge outside the glass and this will occasionally lead to a perforation and destruction of a tube

The distance between tube and electrical apparatus should not be less than 5 feet, better more If the distance is too small, the magnetism of the iron core may deflect the cathode rays, so that the focus wanders about on the anticathode, and blurred outlines on the negative will be the result The tube should not be clamped too tightly in the holder, as the glass is very thin The wires should be fastened securely,

so that they cannot possibly fall out of the eyelets of the tube, for a very severe shock would be the result to patient or operator if a wire became free, and in swinging about came in contact with the patient, or couch, tube stand, etc. It is best to lead the wires from the electrical apparatus along the ceiling on suitable insulators, and then vertically down to the tube If they have to be stretched horizontally from the high-tension apparatus to the tube, they should be at least 8 feet above the ground, so that nobody moving about in the room while it is dark can come in contact with a wire Lack of care in this point might result in a dangerous spark or the destruction of the tube The wires from the terminals of the electric apparatus must lead from the positive pole to the anticathode, so that the current passes through the tube in the correct direction

The space behind the anticathode should remain dark. There should be no flickering There should be *a sharp division between the luminous and the dark half of the tube*, and no fluorescent rings in the dark part (they are due to reverse current) (see page 24) As long as the current used is too weak for the particular tube, there is no sharp division, and the milliammeter will not come to rest as the tube is gradually becoming harder

If the current used is too strong, the tube shows a very bright green light, and the anticathode has a tendency to become incandescent.

With a good tube, the normal current may be exceeded for instantaneous exposures even 100 times, or about 10 times for exposures lasting no more than ten seconds, without fear of injuring the tube, but if it is exceeded for exposures of long duration, the tube is likely to become soft, or even useless if this continues for too long

When a tube is removed from the stand while it is yet warm, it should not be laid on a cold surface It is best to suspend the tubes in brackets fixed on a wall at such a height that the lowest ends of the tubes are fully 6 feet above the ground.

If treated with reasonable care, good modern tubes will have a lifetime of some 500 working hours With carelessness, or want of skill, even the best tubes may, however be destroyed in a short time

Oscilloscope Tubes.—The presence or absence of reverse current can be proved best by an oscilloscope tube This consists of a glass cylinder, 6 to 9 in. long, closed at both ends, into which two aluminium wires are sealed with only a small gap between them (Fig 9) The tube has to be evacuated to a certain degree As long as the current discharges in one direction only, the wire connected with the negative pole shows a

Fig 9

purple fluorescence, and the length of the fluorescent band is in proportion to the strength of the current used Of the second wire, only the point shows a faint light. But if each wire becomes alternately the positive or negative pole, as will be the case when reverse current appears, both aluminium wires will show fluorescent bands,

HOT CATHODE TUBES

The gas tube is unstable and unreliable Its production of X rays depends on its gas content, and this is a very variable factor The desire, therefore, arose early in the history of X rays for a tube in which the production of the cathode stream is independent of the gases which remain after evacuation

The work of Richardson on the emission of electrons by hot bodies and its application to X ray tubes by Coolidge, have solved the problem

It was found that if a tube is exhausted as completely as possible, no current will pass from cathode to anticathode when both electrodes are cold but that if the temperature of the cathode is raised to incandescence, electrons become available and a current will pass in one direction, i e, from cathode to anode, if a high voltage is applied

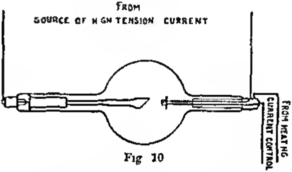


Fig 10

Two main types of hot cathode tubes are in use to day, the Coolidge and the self protected The fundamental principle is the same in each

In Fig 10 we see a diagram of the Coolidge tube A spiral of wire, which serves as cathode, is heated to incandescence by means of a current of about 4 amperes at 12 volts Opposite this is an anticathode, similar to that in a gas tube but consisting of a solid block of tungsten High tension is applied to these two electrodes, and a current then flows from cathode to anticathode

The heating current is usually obtained from a transformer operated by an alternating supply, but it can also be furnished by accumulators or a direct current dynamo Whatever the source is, it must be carefully insulated from earth and the main supply, since the cathode is connected to one pole of high tension unless this pole happens also to be earthed, as is the case in a few types of simple high tension generating plants

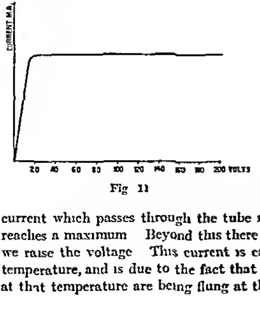


Fig 11

When we heat the cathode spiral to a particular temperature and apply high tension to the tube, we find that as we increase the voltage from zero upwards the current which passes through the tube rises rapidly as in the curve in Fig 11 till it reaches a maximum Beyond this there is no increase in current no matter how much we raise the voltage This current is called the saturation current at the particular temperature, and is due to the fact that all available electrons emitted by the cathode at that temperature are being flung at the anticathode

If, on the other hand, we keep the voltage constant and increase the temperature of the cathode by increasing the heating current, we find that the milliamperage through the tube rises very rapidly as in the curve in Fig 12

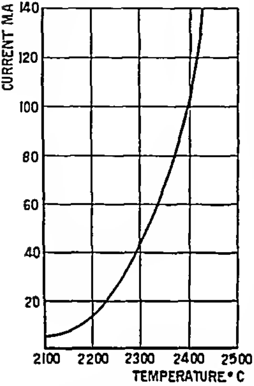


Fig 12

Provided, therefore, that we work at saturation current, we can control the speed of the cathode stream, and therefore the wave length of the resulting X rays, by altering the voltage applied to the tube And we can vary the quantity of the cathode stream, i e, the milliamperage and therefore the intensity of the X rays, by altering the heat of the cathode, i e, the amount of heating current

The two factors are independent of each other, and therein lies the great value of the hot cathode tube

A result of the absence of gaseous molecules, and ionization of the same by collision, is that the glass wall of the hot cathode tube does not fluoresce—it shows no sign of current passing The reason is that the electrons which are reflected off the anticathode to the wall of the tube immediately charge this negatively because there are no positive gaseous ions with which they can combine This negative charge repels any more electrons and so prevents the bombardment of the glass and the production of fluorescence

A second result of this is, however, that the electrons which are reflected off the anticathode and which would radiate outwards to the glass are turned back on to the anticathode in paths similar to the dotted lines in Fig 13 They bombard the sides of the anticathode, and though their velocity is much less than that of those which fly from cathode to anticathode, they are still able to produce X rays where they strike the tungsten In the Coolidge tube, therefore, the whole block of anticathode metal gives off X rays in all directions, a fact which can readily be verified by a pin hole camera or by a fluorescent screen erected behind the tube The intensity of the

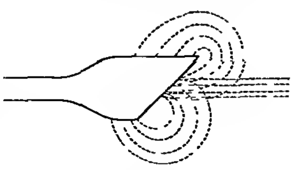


Fig 13

X rays from the focus is of course much in excess of that from other parts of the anticathode

Finally, it must be noted that as the cathode in a hot cathode tube is not bombarded by positively charged gas ions, its temperature does not on this account rise above that due to the heating current even after prolonged use It will, however, rise a little owing to heat radiated from the anticathode, when the latter has become red or white hot owing to cathode ray bombardment, and this will cause a slight increase in the milliampèrage which must be watched, particularly in therapy

THE DESIGN OF COOLIDGE TYPE HOT CATHODE TUBES

It is in the nature of the hot cathode tube that there are only two necks sealed into the bulb, one of which carries the cathode and the other the anticathode No auxiliary anode is necessary during manufacture, and the regenerating device is absent for the obvious reason that there is no gas pressure to be adjusted

The Coolidge tube (see Fig 10), which was the original type of hot cathode tube, is therefore similar in external appearance to the older gas tube, but without the two attachments referred to above It differs from the gas tube in the shape, size and position of its cathode

The cathode in this original form of Coolidge tube consists of a spiral of wire, the two ends of which are brought through the cathode neck to a two pin plug for connection to the supply of heating current The spiral itself is surrounded by a short cylinder of metal which is connected to it and therefore electrically at the same potential The object of this is to focus the stream of electrons which leaves the cathode Without this cylinder these electrons would tend to fly in all directions (Fig 14) The

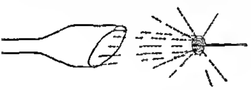


Fig 14

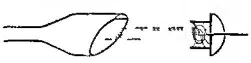


Fig 15

cylinder, however, is negatively charged like the electrons themselves, and so the latter are forced into a bundle as near the axis of the tube as their quantities will permit (Fig 15)

Since the spiral cannot be given a true concave form which would bring the cathode rays to a sharp focus, and, moreover, since there are no gas molecules which have to be bombarded to produce electrons, the cathode in these tubes is placed close to the anticathode

In spite, however, of the cylinder, and the proximity of the two electrodes, the focus of the cathode rays on the anticathode is a comparatively broad one in the older type of Coolidge tube Moreover, the greater the current in the tube, the more divergent becomes the bundle of cathode rays and the broader the focus This fact

is very detrimental to the sharpness of the shadows which are obtained on the film, but it does not matter where therapy is concerned

The difficulty has been overcome by an ingenious invention due to Goetze, which is known as the line focus The hot filament is made in the form of a long thin coil of wire (Fig 16 A) which produces a focus in the form of a long narrow line on

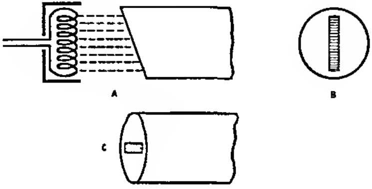


Fig 16

the anticathode (Fig 16 B) This would be useless for radiography if the anticathode were still at 45° to the axis of the tube, because though the focus would be foreshortened to half its actual length, it would still be much longer than it is broad and would throw sharp shadows in one direction and blurred ones in a direction at right angles Goetze's

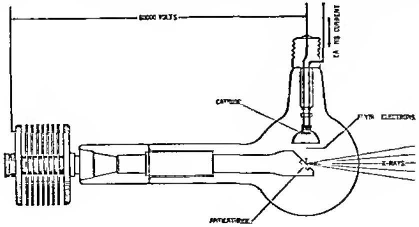


Fig 17

suggestion however, included placing the anticathode face more nearly at right angles to the axis, so that the long focus is foreshortened into a rectangle of approximately equal sides In Fig 16 we see the actual appearance of the focus (B) and also what it looks like when seen from the direction of the film (Fig 16 C)

There is an upper limit to the amount of energy wherewith we can bombard unit area of the anticathode and it is 200 watts per sq mm The advantage of the line focus is that we have increased the area of the focus and therefore the amount of energy which can be passed through the tube, without increasing the apparent area as seen from the film and so diminishing the definition which can be obtained

Coolidge tubes like gas tubes have been built in a variety of shapes to suit different purposes but the fundamental principle remains For instance in tubes for dental radiography the axes of cathode and anticathode are at right angles (Fig 17) The tube can then be brought close to the patient s face with impunity more especially since the negative end of transformers for dental purposes and therefore also the cathode of the tube are earthed i e at the same potential as the patient

Fin radiator and water cooling of the anticathode has also been adopted in some types of Coolidge tube particularly in those which are to act as their own valves in suppressing the reverse half cycle of the non rectified alternating current which is supplied to them in which case a cold anticathode is essential

Tubes intended for therapy at very high tension (200 KV) are constructed with long necks to prevent sparking over outside the bulb

THE SELF PROTECTED TUBE

During the last few years a considerable modification in the design of hot cathode tubes has been made by the introduction of the self protected tube The spherical bulb which had become the normal in an X ray tube has given place to a long glass cylinder the middle of which is surrounded by a short cylinder of brass or

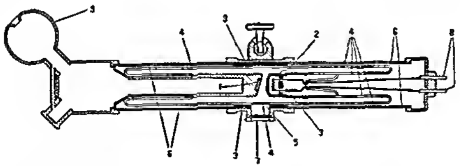


Fig 18

1 Tungsten Anticathode.
2 Hot Wire Cathode.
3 Lead Protection
4 Glass Walls of Tube
5 Opening in Lead Jacket for Primary X rays
6 Insulation Cover over Tube.
7 Filter
8 Plug for Heating Current
9 Water Container

steel lined with lead In this short cylinder is a small circular opening through which X rays emerge The ends of the glass cylinder which project beyond the middle metal cylinder are encased in sleeves of insulating material—either bakelite or porcelain

The self protected tube already exists in a variety of designs and makes for different purposes The one which is most frequently employed in diagnosis is shown in Fig 18 It is equipped with a line focus and with fin radiator or water cooling

The self protected tube employs the same fundamental principle as the Coolidge tube, namely, a hot cathode which is kept at high temperature by a heating current of about 4 ampères at 12 volts

It differs from the Coolidge tube in two important points In the first place, it is not completely evacuated but contains a residue of helium gas This facilitates manufacture and does not interfere with the working of the tube, because each atom of helium contains only two electrons which would be available for ionization by bombardment When we remember that oxygen and nitrogen atoms contain respectively seven and eight such electrons, we see that a tube containing traces of helium will behave very much like one from which all air has been removed

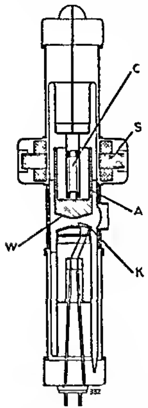


Fig 19

The second characteristic of the self protected tube is the lead lined cylinder in the middle Thereby the tube carries its own protection and its own means for attachment to tubestand couch or screening stand It requires no heavy protected box with awkward means for holding the tube, as was formerly the case Indeed the self protected tube may not be operated in such boxes for fear that the static charges which accumulate within might spark into and ruin the tube

The self protected tube has therefore made a considerable difference in the design of such apparatus as tube stands screening stands and couches, and it is safe to say that the future of radiology lies with the use of some form of self protected tube

Self protected tubes are also employed for therapy Their shape and design for this purpose, differs from that for diagnosis only in the length of the tube Greater length is necessary on account of the greater tension which is employed In all other essentials the tubes for diagnosis and therapy are the same

THE ROTALIX TUBE

A special development of the self protected tube is one which has been designed by Messrs Philips and is equipped with a rotating anode We saw on p 15 that the quantity of energy which can be applied to the tungsten surface of the anode is strictly limited and may not exceed 200 watt per square millimetre Modern diagnostic technique in chest work calls for such heavy currents that the focus of a stationary anode becomes enormous if the maximum permissible load mentioned above is not to be exceeded A large focus however, produces a blurred picture even when the focus film distance is increased to six feet

The Rotalix tube overcomes the difficulty by employing an anode in the form of a truncated cone revolving about a vertical axis (see Fig 19) The focus on this revolving surface is a line focus as in an ordinary self protected tube, but owing to the movement of the anode the surface on which the focus is formed is continually being changed Thereby currents up to 600 M.A. at about 40 K.V can be employed without detriment to the metal

CHAPTER III

THE PRODUCTION OF HIGH TENSION

A STREAM of electrons will not fly from the cathode to the anticathode of an X ray tube and produce useful X rays until we have applied at least 25,000 volts to the ends of the tube We express these high electrical tensions in terms of kilovolts (K V), where 1 kilovolt = 1000 volts For diagnostic purposes we require from 25 to 100 K V, and for therapy from 120 to 200 K V Moreover the current through the tube must always flow in the same direction, so that one electrode is always cathode (−) and the other always anode (+)

The electric supply to our houses has a tension of 200 volts or thereabouts It never exceeds 500 volts and we must therefore adopt measures to convert it to high tension To do this we make use of electro magnetic induction, a phenomenon which was discovered and studied by Faraday and which forms the basis of all electrical engineering He found that —

1 When a magnet is pushed into or withdrawn from a spiral of wire the ends of which are connected to a galvanometer, a current is registered so long as the magnet

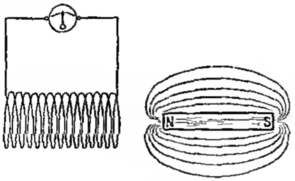


Fig 20

is moving In Fig 20 the spiral of wire on the left is connected to a milliammeter On the right is shown a magnet with the lines of magnetic force surrounding it When the magnet is pushed into the spiral of wire the number of lines of magnetic force enclosed by the spiral is increased.

We say then that the intensity of the magnetic field enclosed by the spiral has been increased When the magnet is withdrawn the intensity is decreased While the magnet is actually in motion one way or the other, that is, while the magnetic

intensity is changing, the milliammeter needle shows a current When the magnetic intensity is constant, no current flows

2 We can reverse the process by passing a continuous current through a spiral of wire, which then behaves like a solid magnet Fig 21 shows a spiral connected to a source of current, and the lines of magnetic force are shown in dotted lines The intensity of the magnetic field so produced depends on the strength of the current, and on the number of turns of wire, and is constant so long as the current is constant In addition, the magnetic field becomes very much stronger if the volume within the spiral is filled with soft iron

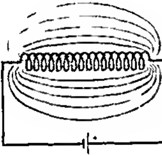


Fig 21

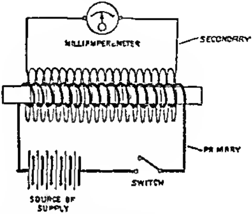


Fig 22

Suppose we take a core of iron and wind on it a layer of insulated wire the ends of which we connect through a switch to a constant supply of electricity Over this layer we wind another layer of insulated wire which has no electrical connection with the first, but the ends of which are attached to a milliammeter (Fig 22) When we close the switch, current will flow through the first layer of wire and will cause the iron core to become a magnet In doing this we raise the intensity of the magnetic field within the second coil of wire from zero to a maximum, and while this change is taking place a current will be registered on the milliammeter We call the first winding the primary and the second one the secondary, the whole arrangement being known as a transformer The current in the primary continues to flow steadily so long as the switch is closed, but the current in the secondary only flows while the magnetic intensity due to the primary current is changing It stops when the magnetic intensity has reached its maximum and while it remains there If now we open the switch we stop the current in the primary and therefore destroy the magoetic intensity in the core While this change from maximum magnetic intensity in the core to zero is going on, a current again is registered on the milliammeter in the secondary

The tension which is produced by induction on the terminals of the secondary depends (1) on the rate at which the magnetic intensity in the iron core changes i e, the rate at which the primary current rises from zero to a maximum, or vice versa, and (2) on the ratio of the number of turns of wire on the primary to the number of turns on the secondary

Two methods exist of varying the amount of the primary current We may either employ a mechanical interrupter which will operate on a large scale like the switch in Fig 22, or else we may use the alternating current supply where the current rises to a maximum, drops to zero, and rises to a maximum in the opposite direction, at a fixed rate, generally fifty times a second

In the first case, we use a transformer which is generally known as a spark coil and sometimes as an open iron core transformer It consists of a straight core of laminated iron on which are wound the primary and secondary, suitably insulated from each other In the second case, where alternating current is employed, we use a core which forms a closed loop of laminated iron, on which the primary and secondary are again wound This is called a closed core transformer

The two types of high tension generators are essentially different in action and will therefore be dealt with separately

THE SPARK COIL

Spark coils were for many years the only form of high tension generating plant available for operating X ray tubes They are now very generally replaced by closed iron core transformers because the latter are easier to handle As, however, there are many coils still in use and the coil has certain advantages in some cases, a study of its mode of action is not out of place more especially since it helps also to explain some of the behaviour of X ray tubes and closed core transformers

The essential parts of a spark coil unit are the coil, the condenser, and the interrupter The coil consists of a straight core of laminated iron on which are wound some 200 turns of thick copper wire, which forms the primary Around this is placed a tube of thick insulating material on which is wound the secondary This is made up of many thousands of turns of thin copper wire either in horizontal layers or vertical sections

If we send a current through the primary, the iron core becomes magnetized The appearance or disappearance of this field, or any change in its intensity, induces electric tensions of short duration in the secondary Their voltage depends on the rate of change of the magnetic intensity and on the ratio of the numbers of primary and secondary turns of wire

The Interrupter has undergone many changes of design in the course of years In the early days of X ray work, interrupters of small size were used They sufficed for the coils and tubes which were then available, but improvements in these two parts of the equipment made large secondary currents possible, and the development of X ray therapy brought about long exposures The small interrupters then used, frequently ran hot, sparked heavily, and had to be cleaned They were replaced by large ones of more than ten times the current-carrying capacity which could interrupt a primary load of as much as four kilowatts and would behave as smoothly and efficiently as electrical motors or dynamos

The type which is most frequently used now, consists of a cast iron pot A, on the lid of which (see Fig 23) is mounted an electric motor with vertical shaft

This drives a turbine (B) in the vessel, which pumps mercury up and sprays it out through two nozzles (CC) on to two copper contacts (DD) which hang down from the lid. It will be observed that while the turbine nozzles (CC) are opposite the copper contacts (DD) which are insulated from the lid, current can pass from the main supply to the primary of the coil when the interrupter is suitably connected. When the nozzles have been rotated further and are spraying mercury against the wall of the pot, no connection exists between DD and no current can flow from main to primary. Two gas taps are fitted to the lid, so that coal gas can be introduced into the pot and kept there while the interrupter is working.

In another type the motor is underneath and drives a pear-shaped steel pot (see Fig. 24) on a vertical shaft. The pot (A) contains mercury and paraffin which form two concentric vertical cylinders under the action of centrifugal force when the pot is rotated. A fibre wheel (B) which moves easily in a horizontal plane carries two copper contacts (CC) and is suspended with its axis eccentric to the axis of the driving motor. The wheel thus dips through the paraffin into the vertical cylinder of mercury when the pot rotates. The mercury pulls the wheel round, and every time one of the copper segments establishes contact a current can flow from the main through the copper segment and the mercury to the primary of the coil. During the rest of the revolution of the wheel, the current through the primary is interrupted.

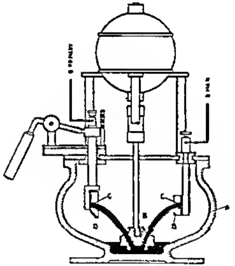


Fig. 23.

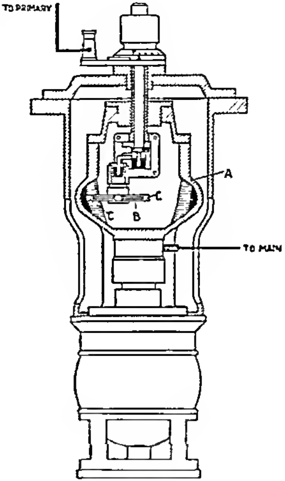


Fig. 24.

The **Condenser** is a piece of electrical apparatus consisting of two metallic plates separated by insulating material No current can flow from plate to plate, but the whole arrangement can store an electric charge and give it out again when desired It is connected across the terminals of the interrupter for a purpose which will be described directly

The general arrangement of a spark coil unit for direct current is shown in Fig 25 The ammeter (A) is an instrument on the switchboard for measuring the primary current The total resistance of the primary circuit can be increased or decreased by means of the variable resistance in the switchboard, whereby the

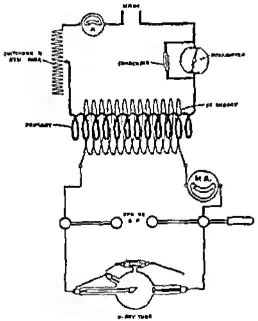


Fig 25

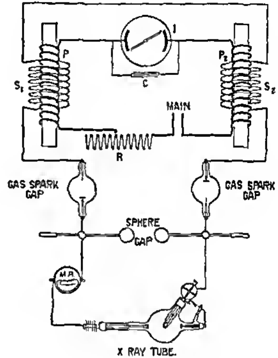


Fig 26

strength of current which flows through the primary winding of the spark coil can be increased or diminished, and therefore also the output of the secondary

The other items to note are the milliammeter in the secondary circuit and the sphere gap Their function is described in the chapter on measurement of X rays, page 72

In one particular spark coil unit which is intended exclusively for deep therapy, both the primary and the secondary of the coil are divided into two parts, and these are placed symmetrically with respect to the interrupter and the X ray tube In the diagram (Fig 26) P_1 P_2 are the two primary windings each on its own core, S_1 and S_2 are the secondaries, and I the interrupter, C is the condenser and R the controlling resistance There are two gas spark gaps in series, one at each end of the secondary, whose function is to suppress the reverse current (see page 24) which is readily produced

at the high tension for which this unit is intended When the unit is employed with hot cathode tubes these spark gaps can be omitted In addition there are, as on the ordinary spark coil plant (Fig 25), a sphere gap and a milliammeter

Interrupters for Alternating Current were designed long after direct current apparatus were already known and in use It used to be customary where alternating current only was available to instal a motor generator consisting of an A C motor and a D C dynamo and then operate the spark coil unit from the D C supply so generated

The perfection of the synchronous motor made possible the use of A C through a spark coil unit without previous transformation A synchronous motor runs in unison with the alternating current in such a way that every position of the spindle of the motor armature in its revolution corresponds to a particular point on the alternating current cycle The zero point of every cycle will always find the armature in one of four definite positions separated by 90°, and the maximum point of the cycle will find it in another one of four equally definite spots If then the mercury turbine device of a gas interrupter is rigidly coupled to the armature, it is possible to arrange matters so that the primary circuit is made when the A.C cycle passes through zero and broken when it has reached its maximum The primary current curve then looks like Fig 27, and it will be seen that the direction of the current alternates—as we would expect—through the primary This would produce secondary break impulses of alternating direction if we employed one primary winding only, which would be useless The primary is therefore equipped with two windings, so arranged that if current flowed alternately through each in the same direction, they would magnetize the core in opposite directions and therefore produce secondary break impulses of alternating direction

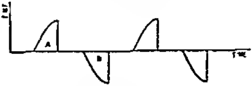


Fig 27

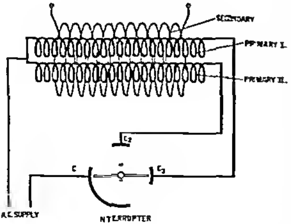


Fig 28

In Fig 28 we see the two windings (I and II), one end of each of which is connected to one pole of the main The second main pole goes to a large common contact (C_1) in the interrupter The separate contacts (C_2 and C_3) are connected to the other two ends of I and II In the half cycle (A) (Fig 27) the contacts C_1 C_3 are joined and current flows through I In the next half cycle (B) (Fig 27) the contacts C_1 C_2 are joined and current flows in the opposite direction through II which however, is wound against I,

so that the direction of the resulting magnetization of the core is the same in each case The secondary impulses then are unidirectional It is interesting to note that these alternating current spark coil units work almost better than direct current ones The reason may be the comparatively gradual increase in the primary current on make

SELF-INDUCTION

When the interrupter establishes contact a current commences to flow in the primary of the coil and sets up magnetization of the iron core This increase of magnetic intensity induces a tension of a certain voltage in the secondary, as we have seen At the same time, however, a tension, other than that of the main current, is induced in the primary because the magnetization of the core which has been produced by the current in the primary winding reacts on those same turns of wire We speak of this effect as "self induction," and of the current so produced as "extra current" Its voltage depends, like that of the secondary current, on the rate of increase or decrease of the magnetic field of the core, on the number of turns of wire on the primary, and on the voltage of the primary current

The self induced voltage is directed against the primary current when the latter is increasing, and tends to keep the primary current flowing when the circuit has been broken The action of the self induction is therefore always opposed to a sudden change in the magnetic "intensity" of the iron core, it prevents the rapid rise of the primary current from zero to a maximum when the circuit is made by the interrupter, and it tends to keep the primary current flowing after the circuit has been broken In doing so, it forms an arc between the interrupter contacts when the break occurs, across which it keeps up the flow of current This arc is known as the "breaking spark," and the current which flows as the "extra current"

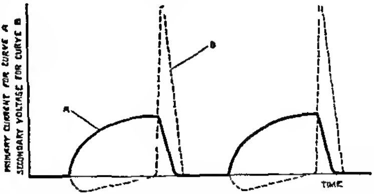


Fig 29

By filling the interrupter with gas or paraffin and by arranging that the distance between the contact and the mercury increases rapidly, after break, we endeavour to extinguish the breaking spark at once and so make the interruption as sudden as possible

We reduce the breaking spark still further by placing a condenser across the terminals of the interrupter—as noted above The extra current now no longer bridges the gap between the interrupter contacts in the form of an arc but rushes into the condenser and charges it up

At make, the primary current rises to a maximum slowly, at a rate depending

entirely on the self induction of the primary winding and beyond our control At break we can and do use artificial means to reduce the current to zero as suddenly as possible

The primary current therefore rises and falls like the curve A in Fig 29, where time is measured on the horizontal axis and the value of the current vertically

Now we have learnt that the secondary voltage, due to induction, depends on the rate of change of magnetic intensity in the core (i e, of current in the primary winding), on the ratio of the number of turns on primary and secondary, and on the voltage which is impressed on the primary *The last two factors are constant in* any particular case, but the rate of change of the primary current is slow at make and very rapid at break We therefore get an induced voltage at the secondary terminals which rises and falls like curve B in Fig 29 Moreover, it has one direction at make and another at break

REVERSE OR CLOSING CURRENT

It will be seen that the secondary impulse at make is slight compared with that at break The current through an X ray tube must always flow in the same direction, and therefore we arrange matters so that the break impulse is the one which generates X rays The make impulse, which is also spoken of as "reverse" or 'closing" current, must be suppressed, as it is harmful to the tube When coils, interrupters, and condensers are properly designed and matched, this reverse current is so much weaker than the break impulse (see Fig 29) that for all ordinary diagnostic purposes it cannot overcome the resistance of the tube and is suppressed. It does, however, rise to unpleasant strength when the coil is called upon to give large currents in diagnosis or kilovoltages from 150 to 200 in therapy through gas X ray tubes (see page 4), and then artificial means must be used to suppress it completely

THE SUPPRESSION OF REVERSE CURRENT

When hot cathode tubes are employed no other device for suppressing reverse current is necessary They have the property of permitting the current to pass in one direction only and act as their own reverse current suppressers within certain limits (see page 11)

A gas tube, on the other hand lets current through either way, when the voltage exceeds the ionization potential (see page 5) and where reverse current is present in quantity, owing to the use of heavy currents for diagnosis or high voltages for therapy, it can be suppressed in one of three ways

The Spark Gap —Before the use of sphere gaps (see page 77) became general spark coils were equipped with two discharge rods to one of which was fixed a point and to the other a plate The distance between point and plate was variable and served as a measure of the voltage obtainable from the secondary The reason why point and plate were used instead of two points lay in the fact that such a gap affords an easy means of determining the polarity of the coil So long as the point is positive

and the plate negative, sparks discharge easily from the centre of the plate to the point (Fig 30) If, however, the point is negative and the plate positive, sparks will not discharge at all readily, there is considerable resistance to the flow of current, and when they do occur they pass from the point to the edge of the plate (Fig 31) This phenomenon was used as a means of suppressing reverse current A point plate gap was

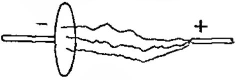


Fig 30

Fig 31

inserted in the secondary circuit so that the plate was connected to the negative pole of the coil and the point to the cathode of the tube (Fig 32) Current could then flow easily so long as the proper pole was negative A reverse impulse, making this particular pole positive and the other one negative, was suppressed Spark gaps are only useful for currents up to 10 M A Above this, other means must be employed

The Mechanical High Tension Valve consists of a rod which is fixed to the end of a spindle of insulating material attached to the axle of the interrupter motor This rod is rotated between two

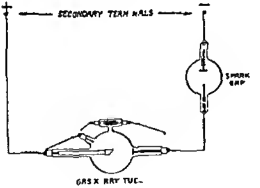


Fig 32

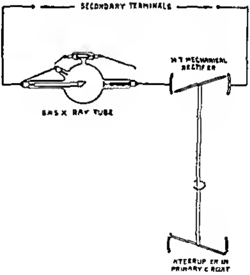


Fig 33

points to which the circuit leading from the secondary to the tube is connected When the rod is in line with these points, current can flow by bridging the two small gaps between points and rod ends as sparks When the rod has been rotated 90°, current cannot pass in the secondary circuit The rod is set so that when the primary current is being broken in the interrupter pat below, the secondary circuit is bridged but at the moment of make the secondary circuit is broken The break impulse can therefore pass through the X ray tube, but the make impulse is suppressed (Fig 33)

The Gas High Tension Valve is a glass bulb similar to an X ray tube, but instead of a cathode and anticathode of the usual pattern, it has an aluminium cylinder for one electrode and an aluminium stem inside this cylinder for the other (Fig 34) So long as the cylinder is negative or cathode the electron stream can leave it in all directions—both outwards and inwards—and the current can flow through the tube, but when the stem inside the cylinder becomes negative and the cylinder positive, the current is suppressed This is because the electrons on leaving the stem can only fly outwards to the inside of the cylinder They accumulate there and set up a static *negative charge which resists the passage of further electrons from the stem to* the cylinder The gas valve tube therefore suppresses the current in one direction. It must always be connected in circuit so that the cylinder is attached to the negative pole of the coil, and the stem to the cathode of the X ray tube These gas valve tubes are generally equipped with some form of regeneration (see page 8) They should be regenerated when their equivalent spark gap exceeds 2 cm

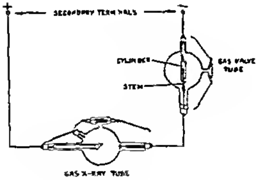


Fig 34

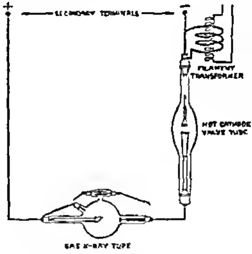


Fig 35

The Hot Cathode Valve Tube is a development of recent years It is based on the property of hot cathode tubes, which we discussed on page 11, of permitting the current to flow one way only, namely, so that the hot electrode is negative and the cold one positive The hot cathode valve differs from the hot cathode X ray tube in that its filament is worked at a higher temperature, the cathode rays from the filament are not brought to a focus, and the anticathode is a large sheet of some light metal. The high temperature of the filament ensures a copious supply of electrons, so that the resistance of the tube is small—1000 volts are sufficient to pass the current through it As a result the electrons fly comparatively slowly and therefore there is no danger of the anode metal heating up—an occurrence which may not take place because it would mean the loss of the valve action of the tube The hot cathode valve tube must be worked at the filament current indicated on the tube If less is used the resistance

of the tube rises, higher voltages become necessary, the electrons fly faster, and X rays will be produced. This is taking place when the glass walls of the tube fluoresce—a condition which must be avoided.

These hot cathode valves are constructed in various sizes—according to the tension of the reverse impulse which they must suppress. In Fig 35 we see one in circuit with a gas tube. For spark coils and diagnostic transformers, small tubes suppressing 100 K V suffice, but large condenser and transformer plants for therapy require valves which suppress impulses up to 200 K V.

THE OUTPUT OF A SPARK COIL UNIT

We have learnt (page 18) that the voltage which is available at the secondary terminals of a spark coil or a closed core transformer depends on two things, namely, the rate at which the magnetization of the core, and therefore the strength of the primary current, changes, and the ratio of the number of turns on primary and secondary. In the case of closed core transformers the first factor is an invariable constant, being determined by the rise and fall of the alternating current, which nowadays has a fixed frequency of 50 per second.

Spark coil units have an advantage in this respect, because the rate of break of the primary current is very largely what human ingenuity and mechanical skill can make it by suitable construction of the interrupter. This is the reason why spark coils of quite moderate dimensions and cost can produce kilovoltages up to 250 where transformers for the same secondary tension are very large and expensive pieces of apparatus. And this explains why spark coils were used for X ray work long after the more easily controlled transformer with its more accurately measurable output came to the front—nay, it explains why even to day a doctor knowing that a spark coil, properly handled, can produce the same results as a transformer, both diagnostically and therapeutically, may, on the score of economy, prefer it to the large and expensive closed core transformer plants, when he wishes to carry out both diagnosis and high voltage therapy. But in doing so he is faced with the necessity of acquiring a greater knowledge and experience of the ways of spark coils than he would need, under other circumstances, of the ways of the transformer.

The voltage, upon which depends the penetrating power of the X rays (see page 60) is, in the case of a spark coil, a quantity which varies with the current taken from the secondary.

The most convenient direct method of measuring voltage (see page 77) is to observe the length of the gap between two spheres, of a certain diameter, which will just be bridged by a spark, and when we place such a gap in parallel with the X ray tube, we call it the equivalent spark gap, and use it to measure the voltage which is applied at the ends of the tube at any particular moment. Suppose now that we find that for a particular setting of our switchboard controls, we are getting 2 M A through the tube when the equivalent spark gap tells us that the voltage is 240 K V. We shall find that if we increase the current-carrying capacity of the tube, either by admitting air in the case of a gas tube (page 8) or by increasing the heat of the

filament in the case of a hot cathode tube (page 12), till 5 M A are flowing, the voltage as measured by the equivalent spark gap will have dropped to, say, 130 K.V The tension supplied by the secondary terminals of a spark coil for one and the same setting of primary controls depends on the current which we pass through the tube When this current is low the voltage is high, and as the current rises so the voltage falls In Fig 36 we see a curve of the behaviour of a coil in this respect

The reason for this is as follows In transforming the primary current to high tension we carry out two distinct changes at each of which we use up energy, i e, do work We first fill the iron core to saturation point with magnetism by converting the electric current when we make the primary circuit. When we break that circuit, the core magnetism vanishes in being converted into current in the secondary circuit The quantity of electricity which is caused to flow in the secondary is determined by the amount of magnetic energy which has disappeared in the core Now in the spark coil the magnetism of the core is not being replaced between one break and the next make of the primary circuit. After the circuit is broken, the coil is disconnected from the main supply till the next make The X ray tube continues to absorb energy, so long as there is any available, but no fresh energy comes into the system till the next "make" of the primary And the more energy the X ray tube absorbs, i e, the more current is passed through it, the more does the secondary voltage collapse The coil, as it were, begins to gasp—it is asked to give more than it has received In the transformer these matters are different The primary is continually taking up fresh energy from the main and is therefore able to give a steady supply of changing magnetic intensity to the core, which passes it on to the secondary In transformers we also come across this collapsing voltage trouble when we take more from the secondary than we give, but the core of the transformer can be designed for a very large output in current (as opposed to mere tension) more easily than that of the coil

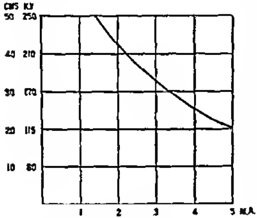


Fig 36

The output from the secondary of a spark cod therefore consists of a series of disconnected impulses, each consisting of a certain quantity of energy given to it by the iron core which received it from the primary circuit When such an impulse has been expended through the tube, there is no more current available till the primary circuit is again made and fresh main current again magnetizes the core The closed core transformer (see page 29) is continually absorbing current from the main and therefore has more energy to give away in the secondary Its secondary current is not impulsive, but rises more gradually to its maximum and similarly falls away

Impulse discharges are, however not wholly disadvantageous for the following reason The voltage which drives the current impulse through the tube rises

abruptly from zero to its crest value and falls away almost as rapidly Practically the whole splash of current thus passes through the tube at the crest pressure, and therefore the speed of the cathode stream and the composition of the resulting X rays is the one due to this pressure The intensity of a beam of X rays varies as the square of the voltage, so that any voltages which are a little below the crest cause an intensity of X radiation which is already much less than that of the crest and which for practical purposes is almost negligible In the coil output almost all electrons of the cathode stream are propelled by the maximum voltage In the transformer output with its alternating current wave form, many electrons fly at speeds due to voltages between zero and the crest They cause current but they do not generate useful X rays And thus gives us the reason why we require a smaller secondary output in milliampères when working with a spark coil, all other factors being equal, to achieve a certain density on a film or a certain biological effect than we do with a transformer The ratio, of course, varies slightly according to the construction of apparatus, but between a good spark coil and a mechanically rectified transformer unit it is of the order of 1 3

THE CLOSED CORE TRANSFORMER

Instead of causing the rise and fall of the primary current by mechanical means such as an interrupter, we can make use of the alternating current, which goes through a complete cycle of changes of value and direction fifty times a second and in such a way that if we plot the value of its tension against time we obtain a sine curve (see

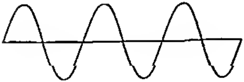


Fig 37

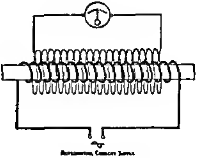


Fig 38

Fig 37) Such tension when applied to a primary winding (Fig 38) will induce in a secondary winding on the same iron core another tension whose presence can be observed by the current which it causes to flow in a suitable galvanometer

We have seen (page 18) that the value of this induced tension depends on (1) the primary tension, (2) the rate of change of the current which it causes in the primary winding, and (3) the ratio of the number of turns on the two windings

When we apply alternating current, the rate of change is a constant given by

the periodicity of fifty per second We are therefore left with the following relationship which was discovered by Faraday —

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

In this, E_1 represents the voltage which is impressed on the primary terminals, and E_2 that which is induced at the secondary terminals N_1 is the number of turns of wire on the primary, and N_2 that on the secondary

Thus if the primary voltage is 160 and there are 140 turns of wire on the primary winding and 100,000 on the secondary, we have —

$$\frac{160}{E_2} = \frac{140}{100\,000}$$

$$\text{whence} \quad E_2 = 114{,}000$$

The production of the high tension current necessary for X ray work is always based on this simple relationship, and it will be noted that by choosing the value of the primary voltage, or the ratio of the primary to secondary number of turns suitably, we can obtain whatever secondary voltage we require

The Construction of a High tension Transformer—The iron core of a high-tension transformer differs from that of a spark coil in being "closed" That is to say that it forms a ring or rectangle (see Fig 39) of laminated iron, upon one arm of which are placed the primary and secondary windings The reason for this is that a closed ring of iron can be loaded with much more magnetism than one in which there are air gaps through which the magnetic lines of force must travel in order to close in upon themselves again Whenever such a gap is present, even when it is quite small, magnetic lines stray away and so the total magnetization which can be achieved in any part of the core is much reduced In spark coils we are compelled to adopt open cores, because we must have as rapid a disappearance of the magnetic field as possible at break We make up for what we lose in the way of magnetic energy by suddenness of break

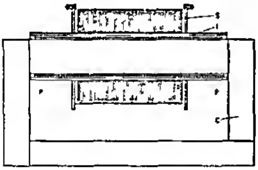


Fig 39

P_1, P_2 Primary winding, S Secondary winding I, Insulating tube, C, Iron core

In transformers this suddenness of break does not exist, and moreover, there is a continual rise and fall of current, a continual pouring of energy into the core We must avoid, at all costs, any air gap, however small, so that magnetic energy may not be lost, and we do so by building up the core so that the thin laminations of special transformer iron are interleaved at the corners The primary and secondary coils (see Fig 39) are separated by a tube of material with high insulating properties

Fig 40 shows such a transformer core with the primary winding in position on one limb and insulated from the iron by some layers of thin insulating material The secondary winding on the other hand has induced in it a voltage up to, say, 150 000 volts Its middle point is earthed and therefore at the same potential

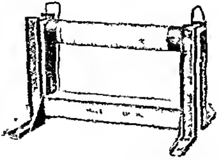


Fig 40

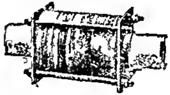


Fig 41

as the core Thus the one end of the secondary is at + 75 000 volts with respect to the core, and the other end is at − 75,000 volts, and insulation must be provided which

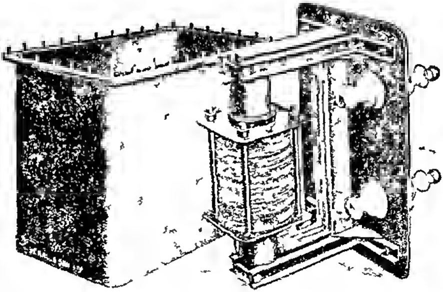


Fig 42

cannot be pierced by such a pressure The insulation takes the form of tubes of special material upon which the secondary is wound *in sections or layers, separated from one* another by sheets of similar material The secondary is built into a compact unit (Fig 41) and then placed in position over the primary (Fig 42)

The whole transformer is placed in a tank filled with oil (Fig. 43). The ends of the primary winding are brought to a plug, and the ends of the secondary are led through heavy insulators of porcelain or other material which pass through the steel lid of the tank.

The object of the oil is two fold. In the first place it is an insulating material which fills out every space in the transformer not yet occupied by wire, core, or insula-

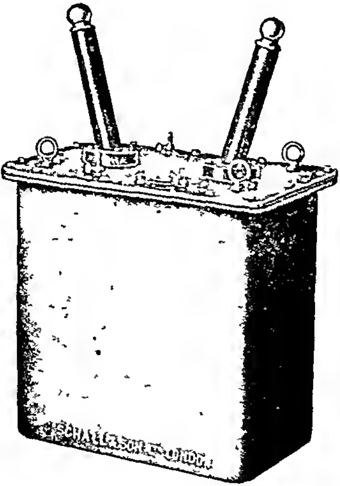


Fig. 43

tion. Thereby it eliminates both direct sparking and also the electric brush discharge which would spray from the secondary winding, producing nitric acid fumes and also burning the insulation.

The second and very important function of the oil is to remove heat by convection (circulation of oil due to heat) from the iron core and, particularly, from the insulating tube between primary and secondary. It is a characteristic of all such materials

that the insulating property decreases very rapidly indeed with rise in temperature A tube which is of sufficient dimensions to insulate against 150 000 volts at ordinary temperatures of, say, 20° C, will insulate against no more than 90 000 volts at 100° C We return to this point later on in discussing the testing of transformers

The Control of the Output from a Transformer Unit.—From the fact that the ratio of primary to secondary voltage is equal to the ratio of primary to secondary numbers of turns of wire, i e —

$$\frac{E_1}{E} = \frac{N_1}{N_2}$$

we see that we can influence the secondary voltage E_2 by varying the primary voltage or the ratio of primary to secondary number of turns

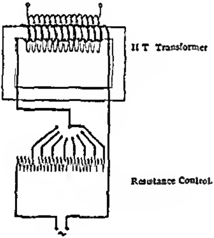


Fig 44

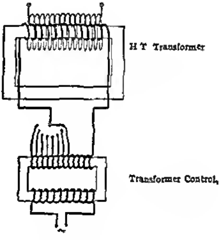


Fig 45

To vary the ratio of numbers of turns would necessitate that a very large number of wires be brought out of the tank, from tappings on the primary winding to crank studs on the switchboard This is very awkward and expensive from a constructional *point of view and would render the machine too cumbersome for use*

The method of varying the primary voltage is therefore adopted, and this again may be done in one of two ways We can either insert a resistance *in series* (Fig 44), which will cut down the voltage of the alternating supply before it reaches the primary, or else we pass the supply through a transformer (Fig 45) and there change its voltage to whatever is necessary

Resistance control has two disadvantages as compared with transformer control In the first place a resistance can only *reduce* a voltage It cannot raise the pressure of a supply to a higher value as a transformer can This is a point of some importance in the design and construction of transformer units though it does not affect their working

The second, and from the operator s point of view more important disadvantage

of the resistance control, is that the reduction which is effected in a supply voltage depends on the size of the current in the resistance

Let us suppose that we want 75 000 volts and 10 milliamperes from the secondary and that this necessitates 150 volts and 10 amperes to be applied to the primary Suppose also that our main supply is at 200 volts Our series resistance must reduce the 200 volts to 150 volts before the current reaches the transformer It must therefore be such that 50 volts (the difference between 200 and 150) will pass 10 ampères through it, and by Ohm's law we have —

$$R = \frac{50}{10} = 5 \text{ ohms}$$

Now suppose that we want to double our secondary current while leaving the voltage at 75 000 We shall have to double the primary current as well so that the product of current and voltage (i e, the power) remains the same in both primary and secondary The same calculation as before shows us that now we require a resistance of —

$$R = \frac{50}{20} = 2\ 5 \text{ ohms}$$

In other words we must reset the resistance control in the primary whenever we alter the amount of current in the secondary if we want the secondary voltage to remain constant

Were we to leave the resistance control at 5 ohms we should in the second case when we are using 20 amperes in the primary, reduce the main voltage of 200 by $V = 20 \times 5 = 100$ *volts We should therefore supply only 100 volts to the trans* former instead of 150 and so we should obtain 50 000 volts secondary instead of 75 000

There is one case where this property of the resistance control is an advantage, namely when we use gas tubes instead of Coolidge tubes A high tension is required to set up the ionization necessary to convey current through a gas tube but once this has been achieved a much lower tension is sufficient If therefore we raise the secondary tension of the transformer to such a point that ionization takes place there will be an enormous rush of current through the tube immediately We have seen that a resistance control automatically reduces the secondary voltage when this increase in current happens thereby safeguarding the tube

The transformer control solves the problem of how to control secondary output at uniform voltage A closed iron core transformer is inserted between the supply mains and the primary terminals of the high tension transformer The primary winding consists of a fixed number of turns of wire, and the secondary which may be wound over it (Fig 45) is tapped at a number of points By using one or other of these tappings we can vary the ratio of windings and therefore also the voltage which we apply to the high tension transformer primary

In practice we employ a control transformer having only one winding instead of two on the closed iron core (Fig 46) This winding is so arranged that the main current flows through a definite invariable number of its turns of wire The current

which it supplies to the primary of the high tension transformer is however obtained by tapping off a number of the turns Here again the ratio of the voltage which is fed into the transformer to that which is taken from it is equal to the ratio of the fixed number of turns to the variable or tapped number If as is generally the case, the number of tapped turns is less than the fixed number, then the voltage delivered to the high tension transformer primary is less than the voltage of the supply etc This arrangement is known as an "Autotransformer because the one winding transforms the voltage of the supply within itself The autotransformer is a comparatively small thing (Fig 47) and is fixed under the trolley which bears the switchboard Only two

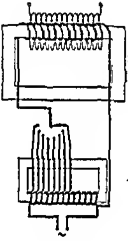


Fig 46

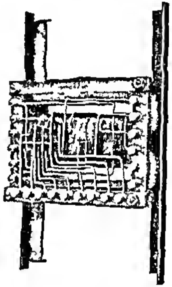


Fig 47

wires go from it to the primary of the high tension transformer whereas a large number go from it to the switchboard immediately above The autotransformer winding is so arranged that we can tap it turn by turn between a lower and upper limit We are thereby enabled to increase the secondary voltage by steps of about 1000 volts at a time

From the foregoing it is evident that a transformer which is to work Coolidge tubes only should have autotransformer control and one which is to work gas tubes as well should have both autotransformer and resistance control

STABILIZERS

The main current is supplied at a certain voltage which is supposed to be quite steady Generally it is 230 or 440 volts Unfortunately in practice this voltage is found to fluctuate quite considerably This may be due to several causes A power station may have a plant which is not equal to the maximum demand and at times

when many lights are turned on the voltage of the supply will drop Another cause is the sudden switching on of heavy loads, e g , a lift, a tramcar starting up, an X ray plant making a short exposure at high output, etc Such loads cause a temporary sudden drop of 5 per cent or 10 per cent in the supply voltage, followed by as sudden a recovery

An alteration in the supply voltage which is not corrected by adjustments on the control table causes a corresponding alteration of the secondary voltage which is applied to the tube and also of the voltage which is driving current through the filament of the cathode Of these two effects, the second, which affects the heat of the filament and therefore the milliamperage in the tube, is the more important A drop of 5 per cent in the supply voltage of 220 will cause a change in the filament current from 5 0 amps to 4 75 amps Those who measure their filament current will realize at once how serious a change this is

Apparatus have been devised whose object is to stabilize or keep constant the main supply voltage The problem is solved in two ways

Provided that the heating current in the X ray tube filament or the high tension current (milliamperage) between the cathode and the anode are kept constant the output of radiation from the tube also remains constant If therefore we can employ any variations, to which the one or the other of these may be subject, to operate relays which shall tend to bring the filament heating current back to its original value, the object is achieved

In one such stabilizer, which is connected in the primary circuit of the filament current transformer, the current in that circuit is automatically reduced when there is a tendency to rise and increased when it tends to fall Since the secondary current of this transformer is the filament heating current and is proportional to this primary current, the heat which is created in the filament is kept constant and therefore also the milliamperage

The second form of stabilizer is connected in the high tension circuit and the current through the tube operates a relay which inserts resistance in the filament heating current circuit when the milliamperage rises and removes the resistance when it falls In this way the temperature of the anode, and therefore the milliamperage, are again kept constant

The primary circuit apparatus is on the whole, the better to use It has no moving parts, it is in the primary or low tension circuit, and it stabilizes the milliamperage at any particular value at which we have set it on the control trolley

The secondary circuit stabilizer requires resetting every time we want to change the milliamperage and therefore stabilized dual control becomes impossible Moreover, this instrument must necessarily have moving parts and of course, be at high tension potential

The advantages of stabilized dual control and low tension to operate the instrument undoubtedly outweigh the one advantage which is claimed for the milliampèrage stabilizer, namely, that it will pass the particular current for which it is set, through any tube, no matter what, within limits, the settings are

THE RATING AND TESTING OF X-RAY TRANSFORMERS

Every transformer is described by its maker as being capable of a certain output This quantity is given in figures and is known as the rating of the transformer The rating should tell us at a glance what kind of work and how much of it a transformer can do In the case of X ray transformers for diagnosis we are chiefly concerned about the maximum current which is available, the voltage at which it passes being relatively less important On the other hand, the available crest voltage interests us most when we want the transformers for therapy, and the permissible quantity of current is a minor item except that we want to know for how long we may keep the apparatus running at a stretch In the case of a unit for both diagnosis and therapy we must make sure that it can give large currents at secondary voltages up to 100 K.V for short periods, or smaller currents at, say, 200 K V continuously

It is evident that it is of very little value to rate a transformer in kilovolt ampères—i e the product of kilovolts and milliamperes—as has been done hitherto when units were described at 10 K V A, 5 K V A, etc The rating must tell us what are the factors which go to make this kilovolt ampère product

We therefore quote a series of figures in rating our transformers, from which the doctor can at once tell for what work the unit is suitable

The first figure is the maximum crest voltage which the transformer can develop when it is run under working conditions From this we can readily calculate the shortest boundary wave length *(see page 61)* of the X rays which are obtainable from the unit Thus the crest voltage is a figure which has a definite meaning to the radiologist. The root mean square (R M S) voltage employed by electrical engineers and often used in foreign countries has no such meaning radiologically Moreover, when the R M S is called the "effective" voltage as is the case in Germany, it is definitely misleading to the X ray worker Another important point to remember is that the crest voltage can be directly observed by means of the sphere spark gap, whereas the R M S is difficult to measure except by indirect methods

All of our transformers can give up to 25 milliamperes at this maximum crest voltage, and this current is amply sufficient for therapeutic purposes

The second figure is the "intermittent" or "diagnostic" rating It is the maximum output obtainable from a transformer when working "all out" It is given in kilovolts and milliampères and represents the output which may be taken from the transformer for periods not longer than 5 seconds This time is amply sufficient for diagnostic exposures and, incidentally, for allowing the milliammeter needle to come to rest when the current is being measured

A third figure called the "instantaneous" rating is sometimes given This is the maximum momentary value of current which can be obtained under the following circumstances We have seen that the secondary voltage of a transformer collapses when too great a load is placed upon it (page 28) In the intermittent rating the load is such that this collapse does not take place We can however get even more current, knowing that the voltage will collapse The point is that the collapse does not take

place instantaneously. It happens almost at once, but for an instant the huge rush of current through the tube is propelled by the uncollapsed crest voltage. This maximum discharge cannot be measured by a milliammeter in the ordinary way because the inertia of the moving coil system of the instrument is too large to follow the rapid rise of the current. This maximum or instantaneous output is what some manufacturers hint at when they say that "Currents up to . . . milliampères can be obtained."

As an example, let us take our Single Valve Unit, No. 39600. The rating is as follows :—

Therapeutic rating, 120 K.V.
Diagnostic rating, 100 K.V., 100 M.A.

This means we can obtain a maximum voltage of 120,000 volts for therapy, and up to 25 M.A. for hours on end. Further, for diagnosis we have the maximum output at 100 K.V. where we can reach currents up to 100 M.A. for long enough to make them measurable on an ordinary instrument, or say for exposures up to 5 seconds. At other voltages the currents are less. We may get 120 K.V. and 40 milliampères for an exposure, or we may get 50 K.V. and 80 milliampères.

The question will immediately be asked—why does the transformer give 10 K.V.A. (100 K.V. and 100 M.A.) at 100 K.V. and only 4·8 K.V.A. (120 K.V. and 40 M.A.) or 4·0 K.V.A. (50 K.V. and 80 M.A.) at 120 K.V. and 50 K.V. respectively?

The answer to this question involves some knowledge of electrical engineering, but a few words may indicate it briefly. A transformer designed for a certain primary and a certain secondary voltage will work at an efficiency of nearly 100 per cent. It does this because the loss of current by conversion into heat, and particularly through the magnetic properties of the iron, is reduced to a very small minimum. In X-ray work, however, we obtain a range of voltages from the secondary by feeding a range of voltages into the primary through an autotransformer. The X-ray transformer, therefore, will work with greatest efficiency at one particular primary and secondary voltage. If we take a higher secondary voltage from it by feeding a higher primary one into it, we increase the amount of current which is lost in purely magnetic phenomena and also that which vanishes in heat. Moreover, the current which is lost magnetically lags behind the primary voltage by 90° or one-quarter of a phase. The current through the tube, on the other hand, is in phase with the voltage. If the magnetizing current becomes too great the current through the tube also lags behind the voltage and we get the condition that the maximum value of the current passes through the tube when the voltage has already fallen away. This condition may be reached in an endeavour to obtain very high voltages for therapy from a transformer made essentially for diagnosis.

When we take less voltage from the secondary than the transformer is designed for, we reduce the primary voltage and also the primary current. The intensity of the magnetic field is therefore also reduced and the output falls below the diagnostic rating. We are then working below the rated maximum output, and because we are not making full use of the iron core we cannot get the full output.

The testing of transformers is rather a laborious process They are first tested as to whether they will give the rated outputs without a collapse of voltage Having satisfied ourselves that this is the case, we test them for performance over long periods By far the largest stresses are due to the high tensions which are present The insulating materials are subject to what is called fatigue Thus a material which can stand up to 80 K V for 10 seconds or a minute may not be able to insulate against more than 50 K V for, say, half an hour Moreover, the temperature of the material is of great importance For instance 1 mm of Bakelite and paper breaks down under 17 K V at a temperature of 20° C At 90° C the breakdown occurs at as low a voltage as 12 K V

As heat is always produced when a transformer is run we see that during long runs a number of factors unite in a sort of vicious circle to the detriment of the transformer's life

Our transformers are run for at least four hours each under the largest stresses produced when in commission, namely, at therapeutic voltage

In addition the calibration of the transformers is made by measuring their secondary tensions by means of sphere gap kilovoltmeters Discharges are allowed to take place, and these causing sudden rushes of current, are a very severe stress

Finally the transformers are put under a tension test for 10 minutes which is arranged so as to produce 25 per cent higher secondary tensions that are given as therapeutic values

COMPLETE HIGH TENSION TRANSFORMER UNITS FOR X-RAY WORK

The closed core transformer can be employed to supply current to X ray tubes in eight different ways

1 We can transform the alternating current to a suitable kilovoltage and supply the secondary current, as it is to a hot cathode X ray tube The current is unrectified alternating current and the hot cathode tube exercises its property of suppressing the half cycle which flows in the wrong direction

2 We can insert one hot cathode valve in the secondary circuit, with the X ray tube, to which is therefore supplied an alternating current with one half cycle already suppressed by the valve

3 We can rectify the alternating current by means of a mechanical rectifier and so supply an alternating current to the X ray tube in which both half-cycles of current flow in the same direction and are therefore both useful for producing radiation

4 We can do the same thing by using four hot cathode valves

5 We can in special circumstances employ only two valves and achieve the same object

6 We can use six valves and connect the plant direct to a three phase current obtaining thereby a rectified current with a small pulsation of not more than 14 per cent

7 We can connect one hot cathode valve and two high tension condensers in circuit with the transformer and obtain a pulsating current whose tension is approximately twice that of the transformer

8 By using two hot cathode valves and two high tension condensers we can generate a current whose tension is double that of the transformer and is continuous with a ripple of only about 5 per cent

(1) NON RECTIFIED UNITS

The alternating current (Fig 48a) which is supplied by the secondary of the transformer, passes through the hot cathode tube which suppresses one-half of it.

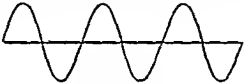


Fig 48a.

A.C as generated in secondary

Fig 48b

Current which passes through hot cathode tube.

The current which is converted into X rays by the tube, therefore takes the form of Fig 48b

It consists of successive impulses each lasting $\frac{1}{100}$ second, and each separated from the next by $\frac{1}{100}$ second

The arrangement of the transformer secondary and the tube is shown in Fig 49

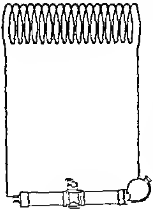


Fig 49

This method would give us all that we require in any form of X ray practice, were it not for the unfortunate fact that there are limits to the amount of unrectified alternating current which we can pass through a hot cathode tube The whole anticathode, or even the focal spot only, will rise to a temperature higher than 1600° C. if the current exceeds a certain value or runs for more than a certain time, and then the property of suppressing the reverse half-cycle ceases If current continues to pass under these circumstances, the tube is rapidly destroyed

For this reason, the units which deliver unrectified alternating current are of comparatively small capacity—30 M.A. at 90 K.V peak in the case of two of them, and 10 M.A. at 60 K.V peak for the dental units. They are adequate for general diagnostic work in small hospitals and as an aid to diagnosis for general practitioners and dentists They can be employed for light superficial therapy, but their usefulness in this direction is very limited

(2) THE SINGLE VALVE UNIT

The perfection of the hot cathode valve has made possible the use of non rectified alternating current without having to pay attention to the limits which are imposed on the use of such currents by the heating up of the anticathode of the X ray tube

The hot cathode valve (see page 26) operates with a filament of larger dimensions and at higher temperatures than hot cathode X ray tubes The voltage which must be applied to its terminals is therefore relatively small (about 1 KV) and the current which it can pass is large The electrons fly comparatively slowly and so no X rays are set up at the other electrode nor is the latter heated up

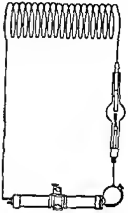


Fig 50

With such a tube in circuit we are able to apply high currents and voltages of unrectified current to a hot cathode X ray tube and even to run the latter with a red or white hot anticathode, since the reverse half cycle does not reach it

The current which is converted to X rays in the tube is again as in Fig 48b and the arrangement of transformer secondary and valve and X ray tube is shown in Fig 50

The single valve unit is deservedly the most popular of all the units which we describe because it has the greatest range of application and costs less than the larger units

It can give as much as 140 M A at 80 K V through a suitable tube for diagnosis and up to 150 K V for therapeutic work

(3) MECHANICAL RECTIFIER

The alternating current at high tension may be rectified by suitable means so that it becomes unidirectional before it reaches the X ray tube Its appearance in a curve is then changed from Fig 51a to Fig 51b Two methods can be employed, namely, the mechanical rectifier and the four valve circuit

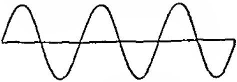


Fig 51a

A C as generated in the secondary

Fig 51b

A C after passing rectifier

The mechanical rectifier is a piece of apparatus which was much used before the coming of the hot cathode valve and was universally used with transformers before the hot cathode X ray tube came and made non rectified current plants possible Now a days the mechanical rectifier is being rapidly replaced by valves and it is safe

to say that no hospital or doctor contemplating a new plant would think of installing a mechanically rectified one, rather than one with valves. Many are, however, still in use, and we will therefore examine their mode of action.

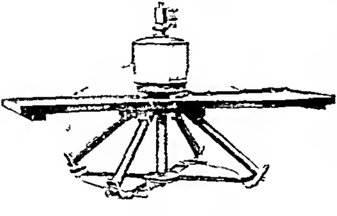


Fig 52.

The mechanical rectifier consists of a cross of insulating material carrying four metal segments which are connected in pairs. The cross is fixed on the shaft of a motor (Fig 52) which runs synchronously with the alternating current. Four fixed contacts are so arranged that they are electrically connected in pairs by means of the segments on the cross whenever these are brought into position by the rotation of the motor.

By synchronism we mean that the position of the motor shaft and therefore of the cross relatively to the four contacts is always the same at any particular moment of the alternating current cycle. We connect the secondary terminals and the ends of the X ray tube to the four contacts as shown in Figs. 53 and 54. Matters are then arranged so that when the alternating current from the secondary terminals (A, B) is at a maximum and A is negative and B is positive, the cross segments connect

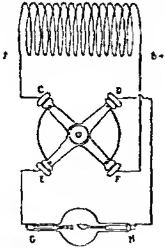


Fig 53.

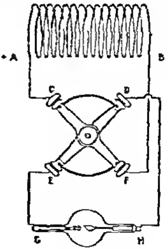


Fig 54.

the contacts C and E and also the contacts D and F as in Fig 53. The current then flows along the path A, C, E, G, H, D, F, B. When half a wave has passed, the alternating current again reaches a maximum but in the opposite direction, so that A is now positive and B negative. The cross by then has rotated through 90° and

now the segments connect C and D, and also E and I as in Fig 54 The current then flows along the path B F, F, G, H D, C, A It will be noted that in each case the terminal G of the X ray tube is negative and H is positive—and we obtain a rectified current in the tube

The synchronous motor is fitted with a special winding which is kept supplied with current till the motor has attained full speed and fallen into step with the supply current The extra winding is then cut out A point of importance is that the motor may "pick up" the positive or the negative phase of the alternating cycle That is to say, that although the motor axle will always occupy certain positions when the zero values of the alternating current take place, the positions in between may be occupied when the current is at maximum in the one or the other direction and this is determined by the direction of the current at the moment of switching on Evidently if we are to have an X ray tube permanently connected to the secondary terminals, the direction of the current in the secondary must be constant This means that the direction of the current in the primary relatively to the position of the mechanical rectifier must always be the same But this as we have seen depends on the particular phase which is picked up by the motor Transformer plants with high tension rectifier

Fig 55

Current which passes through the X ray tube after passing through the rotating rectifier

are therefore fitted with a device (generally a neon lamp with disc and spiral) to show which phase has been picked up, and a current reverser in the primary circuit Latterly the current reverser has been made automatic, and comes into operation by itself as soon as the motor has fallen into step

The mechanical rectifier, in addition to rectifying the current, picks out only a small portion of each half wave, namely, that shown shaded in Fig 55, when the voltage on the secondary terminal is nearly at its maximum The duration of each shaded impulse depends on the length of the contacts C, D, E, F (Figs 53 and 54)

The transformer with mechanical rectifier had certain well defined advantages over the older spark coil unit (see page 19) which made it popular some years ago It has three disadvantages, however, which the hot cathode valve has been able to remove In the first place, it has moving parts which are noisy and can get out of order Secondly, the current passes from the fixed contact to the contact on the disc by way of a spark There are therefore four spark gaps continually in circuit with the X ray tube

The presence of spark gaps in a circuit in which there is high tension and much inductance (the secondary) readily gives rise to what are known as surges The tension in the secondary may, for a fraction of a second, rise very considerably above its normal

value The presence of surges is a danger to the insulation of the transformer and hinders the smooth running of the X ray tube They can be suppressed by inserting coils of wire known as surge coils in circuit, as these absorb the surges when they have been formed Sometimes rods of material with very high resistance are inserted instead as these prevent the surges from being formed The method of fixing such surge coils or high resistance rods on tops of the insulator which carries the secondary leads through the tank lid is shown in Fig 56

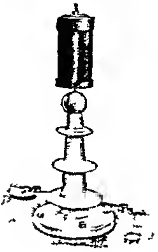


Fig 56.

The third drawback of the mechanical rectifier is that the spark gaps present an appreciable resistance to the passage of current Each gap requires some 7000 volts to be bridged and the four gaps which are in series at any moment therefore, require 28 K.V The transformer may be generating 150 K.V., but the tension available at the ends of the tube will not be more than 122 K V

(4) THE 4-VALVE RECTIFIED UNIT

The 4-valve Rectifier overcomes all three difficulties There are no moving parts and no noise There is no rectifying disc and spark gaps are eliminated Only about 1 K V is necessary to drive current through each valve A secondary tension of 150 K.V does not therefore drop below 148 K.V on the X ray tube since there are never more than two valves in circuit at any one instant

The four valves are connected between the transformer secondary and the X ray tube in the manner shown in Fig 57 where A B is the secondary C D E, F are the valves H G the hot cathode X ray tube and 1 2 3 4 5 the transformers, supplying the heating currents for filaments

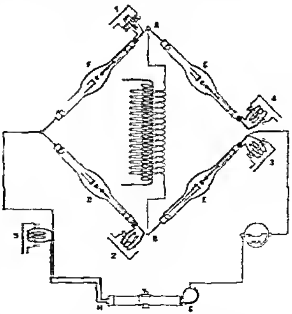


Fig 57

Suppose that in the first half of the alternating current cycle A is the negative pole of the secondary and B the positive pole then the path of the current will be A F H G F B since it must always come from the negative pole to the hot cathode of the valves or X ray tube before reaching the other

electrode It could not, therefore, go from A by way of the valve C because then the cold electrode would be connected to A

In the second half of the wave B is the negative pole, and the current from there, in seeking the hot cathode first, travels by way of B, D, H, G, C, A It should be noted that no other path is open in either case which does not involve the current reaching a cold electrode first in one of the valves As a result we have a rectified current through the X ray tube, as shown in Fig 51b, page 41

The great advantage is that there are no moving parts The apparatus is absolutely silent in operation, and the absence of any spark gaps in the secondary circuit eliminates all possibility of high frequency surges It is essential to have a separate transformer with its own controlling resistance for each valve filament because no two valves are absolutely alike as regards filament resistance

Too much heating current would wear out the valve filament sooner than is necessary, and too little would cause the valve to give off X rays apart from increasing unnecessarily the tension which is lost in passing through the valve

The valves are the only parts of the plant which deteriorate and require renewing They have a life of about 1000 hours when properly used This suffices for seven million exposures of half a second each or for twelve thousand screen examinations lasting five minutes each

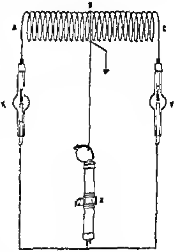


Fig 58

(5) TWO VALVE TRANSFORMER UNIT

It is possible, with the use of two valves only, to obtain a *fully rectified current if we connect* one end of the X ray tube to the mid point of the transformer and the other end to the ends of the two valves which in turn are connected to the open ends of the transformer

In Fig 58 A C is the transformer whose mid point B is connected to the anode of the X ray tube X A and C are connected to the hot cathodes of the valves V_1 and V_2 whose anodes are connected to the cathode of the X ray tube

When A is $-$ and C $+$ then A will be $-$ with respect to B and B will be $-$ with respect to C Current will flow in the circuit AV_1XB In the half B C of the transformer there will be no current, because the valve V_2 stops it In the next half cycle, C is $-$ and A $+$ and therefore C is $-$ with respect to B and B is $-$ with respect to A Current will flow in the circuit CV_2XB and there will be no current in the half A B of the transformer, because the valve V_1 stops it

In each case the current flows through the X ray tube in the same direction — its tension being one half of the total tension of the transformer

If we use a transformer giving a total peak voltage of 150 we can obtain a fully rectified current at 75 K V and, if we have a switch to cut out one valve and connect the X ray tube across the ends of the transformer through the other valve, we get

a half-cycle current up to 150 K.V. Such a plant is therefore very useful for heavy radiography since it can deliver up to 400 M.A. at 75 K.V. and for medium therapy up to 150 K.V.

Its one objection is the earthing of one end of the X-ray tube and so the raising of the other end to 75 K.V. above earth potential. When, however, we remember that many a tube is operated at 100 or 120 K.V., i.e., 50 to 60 K.V. at each end, and that 75 K.V. represents a spark gap of 4¾ in. point to plate, it will be seen that there is nothing much in the objection.

(6) SIX VALVE THREE-PHASE TRANSFORMER UNIT

Hitherto we have dealt with single phase alternating currents, that is to say, currents which rise from zero to a maximum, fall away to zero, and then rise to a maximum in the other direction—according to what is called a sine curve.

There is another form of alternating current which is known as three phase and which, for a variety of technical reasons connected with ease of production and

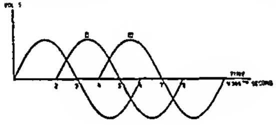


Fig. 59a

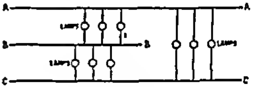


Fig. 59b

distribution, is the kind of current frequently supplied over long distances from the power station to the town or district.

It consists of three alternating currents produced from one armature winding and transformed in three separate transformers or fed into three lines. The curves of these currents are all alike, but at any particular moment there is one-third of a complete cycle between each curve and its neighbour. There is a difference of phase of one third of a cycle between them. If we superimpose the three curves at any moment, they will look like Fig. 59a, in which voltage is plotted vertically against time horizontally.

Matters are arranged so that three lines lead to our house, and between any two of these we can obtain an alternating current of the same voltage. Thus we might get current I (Fig. 59a) from wires A and B (Fig. 59b) to feed lamps on machinery or apparatus, and current II from wires B and C, and current III from wires A and C, the only difference between any of these three currents being that of phase.

The essential condition in a three phase supply system is that we shall not take from any one pair of wires much more current than we take from each of the other two pairs. The smooth running of the machinery at the power station requires that the three phases shall be more or less equally loaded. The difference between phases must not be large—and so a power station generally allows a load of about

10 ampères per phase if loaded alone, but not more—and this is not enough for modern X ray practice.

The hot cathode valve enables us to pass the three phases into the primary of a specially designed transformer and to pass all three in rectified form through the X-ray tube. Fig 60 shows the essentials of the scheme of connections, all details having been left out in order to make the general principle clear A is the triple primary of the transformer and B is the triple secondary, a a a being the supply mains and b b b the three secondary high tension leads

Now it will be observed that the two secondaries X and Z form a four valve unit with the valves 1, 2, 3 4 The secondaries Y and Z also form a four valve unit with the valves 3, 4, 5 6, and the secondaries X and Y do the same thing with the valves 1, 2, 5, 6

Each of these three combinations feeds its current into the two leads P and Q to the X ray tube

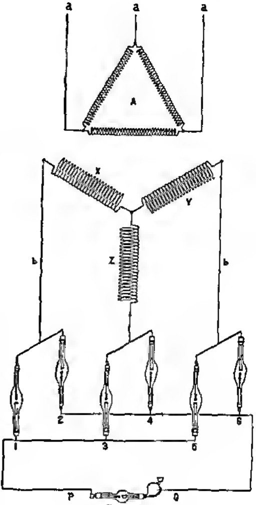


Fig 60

In the tube we therefore get a rectified three phase current In Fig 61a we see the rectification of Fig 59a The dotted lines under the zero line are the reverse half cycles which have been rectified and appear above the zero We therefore get a voltage applied to the tube which varies as shown by the curve in Fig 61b

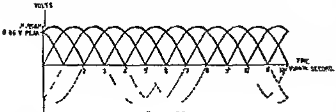


Fig 61a

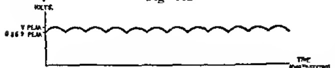


Fig 61b

There are two advantages in using this form of high tension generator

In the first place it can be connected to a three phase system *without any fear of* upsetting the balance of the phases and so running counter to the regulations of the supply company

Secondly, we apply to the tube a voltage which varies 14 per cent between peak

and its lowest value Thus a plant which produces 90 K V at peak, only drops to 77 5 K V at the lowest point. The voltage in fact approximates to a continuous one, and so the resulting X radiation is more homogeneous and has higher intensity (p 63)

(7) CONDENSER UNIT—Villard Circuit

Two condensers, C_1 and C_2 (Fig 62), are connected so that one plate of each is attached to a pole of the high tension transformer The other plate of each condenser is connected to the anode and cathode respectively of the X ray tube A hot cathode valve V is placed in parallel with the X ray tube, but so that the anode of the valve is in contact with the cathode of the tube and vice versa, as shown in Fig 62

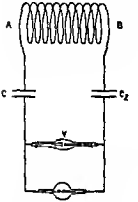


Fig 62

At the peak of one half cycle, A of the secondary is positive and B negative The condensers C_1 and C_2 are charged up each to half the tension of the transformer—say 50 K V —through the valve V No current can flow through the X ray tube, because it is placed so as to suppress the flow in this direction

At the peak of the next half cycle, A is negative and B positive No current can now flow through the valve, but the X ray tube can take it There will therefore be applied to this tube the tension of the transformer plus the tensions of the two condensers so long as their charges last In this way, a pulsating current at twice the tension of the transformer passes through the tube

The unit can also be equipped with a high tension change-over switch which for diagnostic purposes, cuts out the two condensers altogether and puts the valve in series with the transformer and the X ray tube instead of in parallel The unit is then a single valve one, capable of giving up to 100 M A at 100 K V or 140 M A at 80 K V through a suitable tube This unit therefore is very suitable for those who wish to carry out all round radiography and therapy up to 200 K V

(8) CONTINUOUS POTENTIAL CONDENSER UNIT

Experience has shown that in X ray therapy better depth dosage and a greater output of X rays per milliampere are obtained if the tension which is applied to the ends of the X ray tube is continuous instead of being intermittent This has been achieved by connecting condensers of large dielectric strength to the secondary of a high tension transformer

The condensers form a reservoir into which the transformer secondary pours electrical energy and from which the X ray tube withdraws it So long as the current through the tube does not exceed a certain value depending on the capacity of the condenser, the tension supplied to the tube remains almost constant Should the current rise above this value the tension supplied by the condensers fluctuates with the same frequency as the high tension current which charges them

The process is quite analogous to the filling of a bath from a water cistern which latter is itself replenished at regular intervals by a pail of water. So long as the rate of flow of water into the bath is such that the cistern is not emptied between two additions of a pailful of water, the pressure of the water remains constant. If however, the cistern is completely emptied between two pailfuls there will be considerable fluctuation of the pressure.

The arrangement of the apparatus is shown in Fig 63. P is the primary and S the secondary of a closed iron core high tension transformer supplying 125,000 volts. V_1 and V_2 are hot cathode valves and C_1 and C_2 are two high tension condensers of large capacity. T is the hot cathode X ray tube.

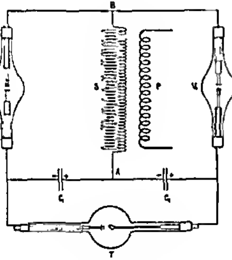


Fig 63

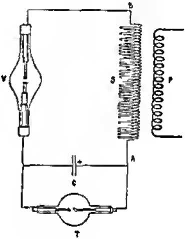


Fig 64

To understand the working of the plant it is best to examine how an arrangement consisting of one-half of this unit, i e, a transformer, one valve, one condenser and one X ray tube (Fig 64), would operate. When B is negative and A is positive a current will flow through the valve (V) and charge the condenser (C) to peak voltage, 125,000 volts. *As soon as A is negative and B positive this can no longer take place* because the valve (V) prevents the flow of current in that direction. The only circuit through which the condenser can pass current is through the X ray tube (T), and this it will do until its whole charge has vanished and the voltage has sunk to zero.

Now the capacity of the condenser is large, so that when it discharges the current which is required, its voltage will sink slowly compared with the frequency of the alternating current. In Fig 65 we see the way in which the voltage from the condenser through the X ray tube varies. Commencing at an instant T_1 the voltage on the X ray tube rises along the curve of alternating tension which is being fed to the condenser by the secondary till the instant T_2 is reached, when the condenser is fully charged. The tension from the secondary then falls away according to the usual curve (shown

as a dotted line) The voltage of the condenser on the other hand slowly drops with flow of current through the X ray tube till at an instant T_3 the voltage of the secondary current again overtakes it and once more raises it to peak voltage at T_4 We have then the curve T_1 T_2 T_3 T_4 T_5 T_6 as the curve of voltage through the X ray tube

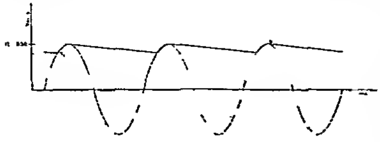


Fig 65

When we double the unit as we do in practice by employing two valves and two condensers both halves of the alternating current wave from the secondary come into use Turning once more to Fig 62 we see that when, at one peak of the wave, A is positive and B negative, the current flows round the circuit A B V_1 C_1 because the hot cathode of the valve is connected to the negative pole (B) The condenser C_1 is charged up to the peak voltage of the transformer secondary No current can flow round the circuit A B V_2 C_2 because here the hot cathode is connected to the positive pole (A)

When the next maximum of tension occurs in the secondary, A is negative and B is positive Current now flows in the circuit B A C_2 V_2 thereby charging up the condenser C_2 whilst B A C_1 V_1 is without current

The condensers (C_1 and C_2) are thus charged up alternately to a voltage of 125 000 each and each discharges current through the X ray tube at that voltage and according to the curve shown in Fig 65 The condensers are in series with respect to the tube so that their voltages at any instant add up and we have a tension applied to the X ray tube of approximately twice the E M.F of the transformer secondary

In Fig 66 we have superposed the two voltage curves from the two condensers $T_1 T_2 T_3 T_4 T_5$ is *that due to the condenser* C_1 whereas $T'_1 T'_2 T'_3 T'_4 T'_5$ is due to condenser C_2 E is the curve which we obtain by adding the two condenser voltage curves This represents the variation of the voltage applied to the X ray tube This variation depends solely, as pointed out above on the capacity of the condensers and the size of the current through the X ray tube The capacity of the condenser determines both its size and its cost, and these two factors increase rapidly At the present time the condensers are made to such a size that they will supply a current of 5 milliampères

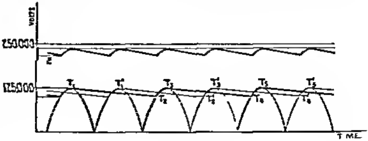
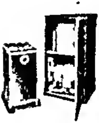


Fig 66

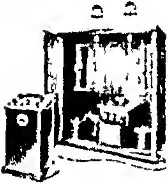
PLATE I

Mobile Ward Unit

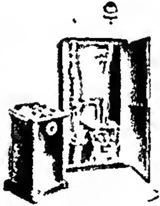
Research Transformer



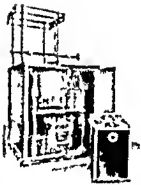
Non Rectified Unit



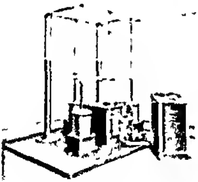
Four Valve Unit



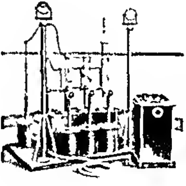
Single Valve Unit



Villard and Single Valve Unit



Continuous Potential Unit



Three Phase Unit

to an X ray tube at a voltage of nearly 250 000 which does not vary more than 5 per cent For all practical purposes this is continuous current

If the current from the plant is increased considerably, the voltage varies much more and the current through the X ray tube is practically a rectified one like that obtained from a transformer with a 4 valve high tension rectifier (see pages 41 and 43)

The condenser plant, when used as described above, with its voltage of 250 000 and its milliamperage of 5, is suitable for therapy only

THE CHOICE OF A HIGH TENSION UNIT

The units which are described on pages 39–50 and illustrated on Plate I serve a variety of purposes and it is often a matter of considerable difficulty for the doctor or hospital authority to decide which type to select The choice is determined by consideration of the work to be done and the funds which are available

The non rectified unit either in cabinet or in the form of a ward set, is suitable for simple radiography and for a limited amount of work on the fluorescent screen It cannot be employed for therapy and, moreover, the exposures which have to be given in the making of a film are necessarily somewhat prolonged owing to the comparatively small output which is available

The single valve unit is a very popular type of apparatus for the general hospital and for all round diagnostic and therapeutic work It produces up to 140 M A at 70 K V, or 100 M.A at 100 K V for radiography, whilst it is suitable for therapy up to 150 K V It can be used to make a radiograph of an adult chest at six feet and 80 K V in one tenth of a second

The two valve unit does the same as the single valve unit, but it has the additional advantage that it gives fully rectified current below 75 K V It produces up to 450 M.A at 50 K.V and can therefore be used for low tension technique in chest radiography

The four valve unit is the one of choice for large X ray departments in which much work is handled It produces fully rectified current up to 120 K V and will also give 450 M.A at 50 K.V

The six valve unit is employed chiefly for low voltage long distance chest technique, but it is suitable for all round radiography as well It develops 600 M.A at 50 K.V, and can produce a film of an adult chest at six feet in one twentieth of a second

The Villard unit is for therapy only, with a pulsating current. It can however, be built to be used as a single valve unit as well and it then forms a useful plant for radiography and any form of therapy including deep therapy up to 200 K.V

The continuous potential unit is for therapy only Its advantage lies in the fact that it produces a tension which is not intermittent The dose of X rays obtained at a depth, as compared with that on the surface, grows greater as the tension applied to the tube grows more continuous The unit is, therefore, primarily for deep therapy

CHAPTER IV

SOME PHYSICAL EXPLANATIONS

ELECTRONS AND ETHER WAVES

MODERN physics assumes a medium known as the ether which pervades all space not occupied by matter Its nature is a matter of speculation, but we ascribe to it the property of transmitting light from one body to another

Newton discovered that ordinary white light, when passed through a prism, forms a spectrum of colours Later on, Huyghens showed that when two beams of light of the same colour met in the same spot it was possible under certain circumstances to produce darkness at this spot The explanation given was that the two beams of light were two trains of ether waves, and that, when darkness resulted at the spot where they converged, matters had been so arranged that a wave crest in one train of waves coincided with a wave trough in the other, whereby their effects were neutralized Moreover, the colour of the particular light is due solely to its wave length—and what Newton had done with the prism was to analyse a collection of wave lengths into component parts which range from long waves at the red end to short ones at the blue or violet end of the spectrum

The next step came when Clerk Maxwell worked out the electromagnetic theory of light Faraday had shown that an electric current in a wire is always surrounded by a magnetic field, that the intensity of this magnetic field varies with the strength of the electric current, and that, therefore, a pulsating electric current produces a pulsating magnetic field Moreover, in a wire loop enclosing a space in which a variable magnetic field pulsates, there is set up an electric current which varies in tune with the magnetic field

Maxwell showed that if we regard magnetism as being a condition of strain in *the ether which is transmitted through space with a velocity of light—namely, 300 000* kilometres per second—we may regard Huyghens' ether waves of light as being waves of magnetic intensity He called them electromagnetic waves because of the electric origin of magnetic phenomena, and he prophesied that we would find that the waves of visible light were but a small group of wave lengths of a huge spectrum of electromagnetic waves containing wave lengths both longer and shorter than those of light The longer waves were subsequently found by Hertz and Marconi and the shorter ones by Röntgen

The nature of X rays was for a long time a baffling secret It was known that the cathode rays which produce them are corpuscular, that is to say, that they consist of particles flying at great speed and that these particles are units of negative electricity—electrons As X rays have a few properties in common with cathode rays,

it was thought for a while that X rays are also corpuscular, but gradually it came to be suspected that they are also a wave motion of the ether like visible light and differing only in wave length

This was confirmed by Friederich and Knipping who, acting on the suggestion of von Laue, used the regularly arranged planes of atoms in crystals as a natural grating (see page 79) to produce those same interference phenomena in X rays which Huygbens with other methods had produced in visible light

This important discovery assigned to X rays a place in the spectrum of electro magnetic waves which Maxwell had foretold We must readjust our conception of the spectrum and enlarge it considerably We must realize that the spectrum consists of ether waves of every conceivable wave length which differ from one another in nothing except just that wave length

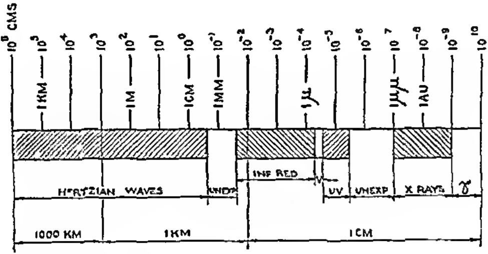


Fig 67

Hertzian waves = wireless waves	V = visible spectrum
Unexp = unexplored region.	U V = ultra violet spectrum
Inf red = infra red heat radiation	X = X rays
	γ = gamma rays of radium

In Fig 67 we see in diagram how the various kinds of radiation are arranged in this extended electromagnetic spectrum It has been necessary, as it were, to foreshorten the diagram at the wireless end and to magnify it in the region of the shortest rays in order that their description may be inserted Thus if we made the region of the spectrum from infra red to γ rays 1 cm long we would find that half the spectrum of wireless or Hertzian waves and an unexplored region down to the infra red would be 1 kilometre long and the remainder of the spectrum of the wireless waves would be 1000 kilometres long This gives us an idea of how small a trifle of the whole range of ether vibrations is perceived by the eye

The figures at the top of the illustration (Fig 67) are the wave lengths in centimetres Below them are shown the points where the wave length is 1 kilometre (K.M),

1 metre (M.), 1 centimetre (C.M.), 1 millimetre (M.M.), 1 micron (μ = one-thousandth of a millimetre), 1 millimicron ($\mu\mu$ = one-thousandth of a micron, i.e., one millionth of a millimetre), and 1 Angstrom unit (A.U. = one ten millionth of a millimetre, i.e., one hundred millionth of a centimetre or 1 cm. $\times 10^{-8}$). These units, which are multiples or fractions of a centimetre, are merely employed because the centimetre itself is too small for very large and too large for very small wave lengths. The Angström unit is the wave length measure which is always used in radiology. The Greek letter λ is frequently employed to denote "wave length." The wave length of the X rays used for medical purposes varies between about 1 and 0.15 A.U. The gamma rays of radium have a λ of 0.1 A.U. or less. Violet light has a λ of 3800, green light 5000, and red light 7600 A.U.

The discovery of the electron and of the structure of the atom has proved the electromagnetic nature of all these radiations, and the truth of Maxwell's theory.

An electric current is a stream of electrons. A single electron in flight is accompanied by a magnetic field whose intensity depends on the speed of the electron. An electron which is rapidly altering its speed produces a magnetic field of changing intensity. An electron which is oscillating to and fro will therefore set up a train of waves of magnetic intensity, and these, travelling outwards in all directions, constitute a beam of electromagnetic rays, which may be wireless waves, or heat rays or visible light, or ultra violet or X rays, according to the wave length.

What causes the oscillations of the electron, and what do we know about them? In the case of wireless telegraphy, we make streams of electrons surge to and fro on comparatively long paths from one condenser to another, thereby producing very long waves of magnetic intensity in the ether. Heat rays—i.e., those rays with a wave length which is just longer than that of visible light and which produce the sensation of heat when absorbed by the body, because they cause atoms and molecules as whole units to vibrate—are due to electrons surging to and fro on paths whose length is of atomic or molecular dimensions.

The atoms and molecules of bodies which are at high temperatures and are emitting heat rays, are in a lively state of oscillation and rotation—moving their whole groups of electrons with them in the process.

Visible light and particularly X rays are due to electrons moving to and fro on paths which are much smaller than atomic dimensions.

It can be stated that all production and absorption of X rays takes place within the confines of the atom.

SOMETHING OF THE MODERN ATOMIC THEORY

Since von Laue proved that X rays are but a short wave radiation exactly similar to ordinary light in everything but wave length, the properties which have been described in Chapter I, and which were empirically discovered, are seen to be related. We will now attempt to describe in simple language what are the physical laws which govern X rays.

Matter was for many years believed to consist of minute indivisible particles

called atoms Some seventy kinds of atoms were known, which differed from each other in their physical and chemical properties These seventy different kinds of matter were called elements and were believed to be immutable

The weight of the elemental atoms was determined by various difficult methods, and these weights were expressed as multiples of the weight of the hydrogen atom, which, being the lightest, was taken as unity

Prout, an English doctor, formed a hypothesis during the early years of last century that the atoms of all elements simply consist of groups of hydrogen atoms, and that hydrogen is, in fact, the primary form of matter On this assumption, however, all atomic weights would have to be whole numbers, since the hydrogen atomic weight is unity, but as several of the experimentally determined atomic weights were far removed from whole numbers, the hypothesis had to be abandoned

The discovery of radio activity and X rays, and the work of J J Thomson, Rutherford, Bohr and many others during the last thirty years has entirely modified our conception of atoms and has established a modern atomic theory which is very similar to the hypothesis enunciated by Prout

We now know that the atom is divisible and that it is not unlike a minute solar system consisting of a central body comparable to the sun, and a number of smaller bodies, similar to planets, grouped round the central body on imaginary spherical or egg shaped shells at varying distances

These planetary bodies are unit negative charges of electricity They are, in fact, electrons like those of the cathode stream (page 2), and their mass, electric charge and velocity have been accurately measured

The central body is known as the nucleus and consists of one or more units of matter which we call protons each of which carries a single positive charge of electricity The mass of one proton is eighteen hundred times that of one electron, and whereas the unit of negative electricity occurs by itself as an electron and can be isolated as such, the unit of positive electricity always appears to be associated with matter as a proton and has never yet been separated

In the nuclei of the heavier atoms there are, in addition to the protons, one or more electrons which, from their position, are known as nuclear electrons They reduce the effective positive charge of the nucleus somewhat Thus a nucleus consisting of sixteen protons and eight nuclear electrons has an effective positive charge of eight

The figure which denotes the effective positive charge of the nucleus is called the atomic number of the particular element The atomic weight on the other hand, is given by the actual number of protons in the nucleus For most elements the atomic weight is roughly twice the atomic number A table of atomic numbers and weights is given on page 168

Formerly the atomic weight was regarded as the important characteristic of an element To day we know that the atomic weight is only of secondary importance The atomic number, or, as we have seen, the effective positive charge on the nucleus, determines the chemical and physical properties of the atom

The actual structure of nuclei is still rather uncertain and remains a subject

of investigation It is known that the hydrogen nucleus consists of one proton carrying unit positive charge An interesting nucleus is that of helium, which contains four protons and two electrons, thus giving an atomic number 2 and an atomic weight 4 It is shot out of radio active bodies and was given the name α — particle before it was recognized to be the helium nucleus

Another interesting point is that an element may have more than one atomic weight but always the same atomic number That is to say, that the number of protons and electrons in the nucleus may vary, but the difference, i e, the effective positive charge, remains constant The various atoms all exhibit the chemical and physical properties of the one element having that particular atomic number Such atoms of varying masses are known as isotopes of the particular element They were only recognized after the discovery of radio activity, and are the reason why the atomic weights of some elements, which occur in nature only as mixtures of isotopes, are far removed from whole numbers One of the best instances is the atom of chlorine, whose atomic weight of 35 5 is due to a mixture of two isotopes, whose weights are 35 and 37 respectively Another instance is lead, which occurs in no less than eight isotopes

This explains why Prout's hypothesis would not gain acceptance till the existence of isotopes had been suspected and proved

For the purpose of radiology, the most important part of the atom for the present is the group of electrons which are arranged on imaginary shells around the nucleus The atom, as a whole, is an electrically neutral body, the effective positive charge of the nucleus being neutralized by the negative electrons outside The atomic number of an element, therefore, also denotes the number of these external electrons, which are described by a variety of terms indicative of their position in the atom, such as extra-nuclear, ring or shell electrons

As we pass from the hydrogen atom through the whole list of elements arranged according to their atomic numbers, we find that at each step the atomic number increases by unity That is to say, that each element has one more charge of positive electricity on the nucleus and one more extra nuclear electron than the element with the next lower atomic number

The arrangement of extra nuclear electrons about the nucleus follows a definite plan In the first place, the imaginary shells on which the electrons are grouped are situated at certain definite positions about the nucleus Secondly, extra nuclear electrons rest only on these spherical or ellipsoid (egg shaped) shells and nowhere else The electrons can jump or be moved, as we shall see later (page 58) from one shell to another, but they do not come to rest between shells

The innermost shell, which is nearest the nucleus, is called the K shell or ring Proceeding outwards we come to the L shell, then to the M shell and N, O, P, Q shells

It has been found that the K shell can accommodate two electrons and no more The hydrogen atom has only one extra nuclear electron situated on the K shell The helium atom has two, and both are on the K shell. The lithium atom, however, has three such electrons, two of which are on the K shell and one on the next or L shell

Again, the L shell will not accommodate more than eight electrons, and when, by adding one electron per element as we pass step by step to the heavier atoms, we have

reached the atom of sodium, whose atomic number is 11, we find that the L ring is full up and one electron is now accommodated on the next, or M, ring We can form a theoretical picture of the sodium atom somewhat like Fig 68

The M ring accommodates 18 electrons after which the N ring receives electrons up to the number 32 Of the O, P, and Q shells we have less evidence, but it seems that their capacity for electrons decreases again as we go farther from the nucleus Sommerfeld gives the following arrangement for the atom of radium —

Shell	K	L	M	N	O	P	Q
No of electrons	2	8	18	32	18	8	2

From what has been said above, it will be realized that any alteration in the composition of the nucleus, by removing or adding protons or electrons in such a way that the atomic number is changed, involves a conversion of the element into another element This phenomenon occurs spontaneously in radio active bodies, but it is exceedingly difficult to imitate artificially and has only been accomplished in the laboratory It is of course, accompanied by a suitable readjustment of the number of extra nuclear electrons

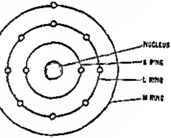


Fig 68

On the other hand, the number of extra nuclear electrons can, and very readily does, suffer change in an atom in which the nucleus remains constant We find that from a variety of causes electrons are continually being added to or removed from the shells surrounding the nucleus The atom then has more or less extra nuclear electrons than are necessary to keep it electrically neutral In the first case it acquires a negative charge, and in the second a positive one It is now called an "ion" or "wanderer," because its charge causes it to wander one way or the other under the influence of an electric force, and the phenomenon is known as "ionization"

It is evident that the proof and acceptance of this modern theory of atoms has thrown much light on chemical problems For the purposes of radiology, attention must be drawn quite briefly to one point Chemical compounds consist of aggregations of atoms which are linked together in definite quantities and proportions It *is most likely that the actual links are those extra nuclear electrons which are situated* on the periphery of the atom Such aggregations are known as molecules They are more or less stable according to their nature, and may vary from so simple a group as the hydrochloric acid molecule, in which there are one hydrogen and one chlorine atom, to the highly complicated molecules of organic compounds such as cell plasm albumin, cholesterine, etc, which go to make up the human body and consist of whole chains or rings of atoms of hydrogen, carbon, nitrogen, oxygen, and other elements The point is that if we can imagine some agency (and as we shall see, X radiation is such a one) which could disturb the peripheral electrons of the atoms we can picture the links of such chain or ring molecules being withdrawn and the whole complex molecule tumbling to pieces It is for the biochemist to say what are the biological results of such decomposition of complex molecules

THE CHARACTERISTIC RADIATION OF ATOMS

Let us once more examine the model of the atom which was discussed on page 55 The following curious interdependence of ether waves and electrons has been found to exist An extra nuclear electron which moves from a shell nearer the periphery to one which is nearer the nucleus and on which, for reasons to be discussed later, there is an electron missing emits an ether wave or a train of ether waves in the process Moreover, the wave length of the resulting radiation depends strictly on the position of the two shells relative to the nucleus and on the size of the atomic nucleus, i e, on the atomic number of the atom Thus if in Fig 69 electrons jump from any of the outer shells on to shell K, they will emit rays of certain wave lengths We call these rays K radiation, and we differentiate between their wave length by calling them K_1, K_2 K_3 rays according to whether the jumping electron came from the L M N, etc, shell (see electrons 1, 2, 3, in Fig 69)

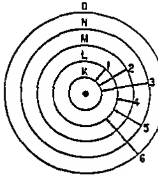


Fig 69

A further series of such wave lengths is produced by electrons jumping (4) from M to L, (5) from N to L and (6) from O to L, and these are known as the L radiation The same is true of M radiation and N radiation, etc Each element can thus be identified by its "characteristic" spectrum of a variety of wave lengths

We are therefore dealing in the atom with a conversion of energy The various shells can be regarded as several levels of potential energy, and when the electron falls from a level of higher potential energy (nearer the periphery) to one of lower potential energy (nearer the nucleus) a certain amount of energy is freed and takes the form of radiation Moreover, the amount of energy thus freed is a very definite one which is always the same for the particular jump in the particular atom and it is called the energy "quantum"

THE CHARACTERISTIC ABSORPTION OF ATOMS

Just as the electron gives up energy in the form of characteristic radiation when it falls or jumps from one shell to another nearer the nucleus, so is energy required to lift an electron from a shell near the nucleus to one farther out, or to make it fly right out of the atom into space The energy which is necessary may be supplied either by ether waves such as ultra violet rays or X rays, or else an electron from outer space such as a cathode ray electron may fly through the confines of the atom and drive an electron from its position on a shell into space Such electrons which leave atomic shells to fly about in space are sometimes called photo electrons because they were first noticed when metals were subjected to the influence of ultra violet rays Now we have seen that electrons falling on to the K shell produce K radiations which have a certain wave length and when they fall on to the L shell L radiation of a longer wave

length results, etc. To lift an electron from the K shell requires the energy of a wave length slightly shorter than K radiation, because the fact that in a neutral atom all shells are already occupied by electrons necessitates that the electron be lifted right out of the atom. Again, if the radiation which penetrates the atom is not of short enough wave length to excite photo electrons from the K shell, it will excite those from the L shell or from the M or N or O shells. The result is that a beam of X rays containing every conceivable wave length, i.e., having a continuous spectrum, will, after passing through matter, have certain wave lengths removed. The energy of these wave lengths will have been absorbed in setting photo electrons in motion, and the spectrum of the original radiation, after passing matter, will show a series of gaps called absorption lines where these wave lengths have been removed.

The amount of energy so absorbed from the beam of rays is again a definite one which is always the same for the particular jump of an electron which it causes in a particular atom, and is called the energy "quantum."

The mathematical formulation of these relationships is due to Planck, and is known as the quantum theory. It is that

$$E = h\nu$$

where E is the quantum of energy given to or taken from the electron by the absorption or emission of a radiation whose frequency is ν, and h is a constant known as Planck's constant. The frequency, of course, is merely a reciprocal way of expressing the wave length ($\nu = \frac{c}{\lambda}$ where c is the velocity of light), and so we see that the energy quantum is the greater, the shorter the wave length.

The Intensity of X Rays corresponds to the "brightness" of a source of visible light. It is defined as the quantity of X-radiation which traverses or is available on unit area (1 square centimetre) in unit time. It varies with the number of electrons which fly in the cathode stream and with the speed at which they fly. The number of electrons per unit time is defined as the current in the tube, and their speed is directly proportional to the tension on the ends of the tube. We say therefore that the intensity varies with the current and the voltage.

The intensity varies more rapidly with the voltage than with the current. It is directly proportional to the current, i.e., a tube working at 50 kilovolts and 4 milliampères produces twice as great an intensity as one working at 50 kilovolts and 2 milliampères. On the other hand, the intensity varies as the square of the voltage, i.e., a tube working at 100 kilovolts and 2 milliampères produces four times as great an intensity as one working at 50 kilovolts and 2 milliampères.

A limit is, however, placed to the increase of the quantity by the maximum power which the apparatus can produce and the maximum current which the individual tube can stand without being damaged. As the duration of the exposure depends on the available quantity of X rays, it must be our aim to perfect tubes and apparatus so that great quantities of X rays can be produced.

THE INTENSITY OF X RAYS VARIES WITH THE DISTANCE

The intensity of X rays diminishes rapidly as the distance between the origin (anticathode) and the object increases In this it behaves like the intensity of ordinary light and *varies inversely as the square of the distance*

The reason for this is best explained by the well known diagram (Fig 70) appearing in all text books on light The illustration shows how the intensity of radiation coming from a point varies with the increasing distance We consider the source of radiation to be at the point of the pyramid, and place a certain rectangular area at a certain distance from this point. The illustration shows that at *twice* this distance the area which is exposed to the radiation is *four* times the size of the above rectangle, at *three* times the distance, that area has become *nine* times the size of the original rectangle We see, therefore, that the single rectangle referred to above, which is struck by the full radiation at the first distance, is struck by only

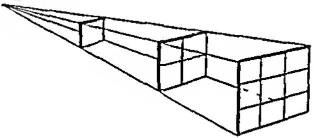


Fig 70

one-quarter of that radiation at twice the distance, and one-ninth of it at three times the distance A photographic plate exposed at 40 cm from the anticathode requires, therefore, four times as long an exposure to assume a certain tint as a plate exposed at a distance of 20 cm

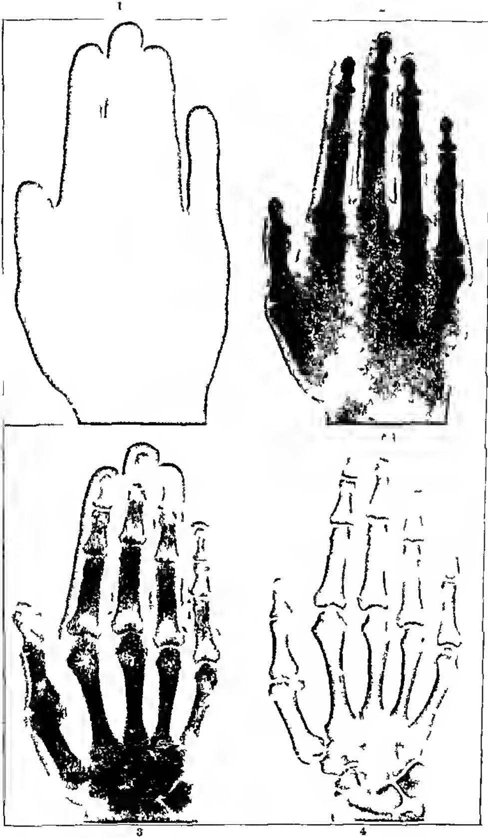
The Quality of X Rays —The voltage influences not only the intensity of the radiation from an X ray tube as described in the last paragraph, but also their quality or penetrating power

When X rays were first discovered it was found that if the tension, i e, the number of volts applied to the ends of the tube, altered, the nature of the rays which were produced was also changed When the tube was in such a condition that current would easily pass, even at comparatively low voltages (say 30 000), rays were obtained which had low penetrating power On the other hand, a tube which resisted the passage of current and necessitated high voltage (say 90 000 to 120,000) gave rays of high penetrating power

This variation in the *quality* of rays was expressed by calling them "soft," "medium," and "hard," with a number of intermediate designations such as "medium soft," "medium hard," etc

On Plate II we see four photographs of a hand taken under varying conditions The first one is with a "very soft" tube (about 30,000 volts) and shows the hand as a black shadow with the bones only very slightly indicated The rays penetrated only thin portions of flesh

No 2 shows the effect of rays produced at 40 000 volts which were slightly


1
3
4

harder and were called "soft" The flesh has been penetrated but not the bones, which appear quite black

No 3 was made with "medium" rays at 70,000 volts, and shows good penetration of the flesh everywhere, and some penetration of the bones

No 4 was made at 100 000 volts with rays so "hard" that the flesh was penetrated to the extent of being rendered invisible, whilst the bones show very considerable penetration in parts

The cause of this variation of "quality" of rays was found when Laue showed them to be a wave motion like ordinary light It is a variation in the wave length of the rays which makes them more or less penetrating The "soft' rays which do not penetrate are those with long waves whilst decreasing wave length is accompanied by increasing penetrating power Thus a definite relationship between quality of X rays and impressed volts was long suspected We used to say that "the greater the voltage on the ends of the tube the faster do the electrons of the cathode stream fly And the faster the flight of the electron, the greater is the impact on collision with the anticathode and the harder are the X rays which result"

Einstein then showed from theoretical considerations and Duane and Hunt from actual experiment, that there is indeed such a relationship and that the wave length of X rays is inversely proportional to the exciting voltage If we denote the voltage in kilovolts by V and the wave length in Angstrom units by λ, then for an electron which is completely stopped, i e, which gives up all its energy

$$V = \frac{12\ 4}{\lambda}$$

The quality of X rays is therefore the property which corresponds to the colour of visible light Its measurement was a puzzle in earlier days, but now resolves itself into accurate determination of the impressed voltage or of the actual wave length (see page 77)

A table will be found on page 170 which shows the relationship between the old description of X ray quality and the modern notation in kilovoltages

The production of high voltages is the function of the electrical apparatus, which becomes larger and costlier as the voltage which it must produce rises

THE PRODUCTION OF X RAYS BY CATHODE RAYS

The energy of the flying electrons of the cathode stream is converted in three distinct ways, when those electrons collide with the atoms of which the anticathode consists

In the first place, such an electron, whose speed depends on the voltage which drives it, will suffer a retardation or even complete stoppage of its flight when a collision with an anticathode atom takes place We have seen on page 54 that such an alteration in the motion of an electron gives rise to a train of electromagnetic waves The greater the speed of the electron the greater is its energy and the greater the amount

of energy destroyed by collision, the shorter is the wave length of the electromagnetic waves (X-radiation) which result. This is the first and, for the radiologist, the most important conversion of electronic energy at the anticathode We will examine it in some detail

THE COMPOSITION OF THE X RAY BEAM

We would be tempted to assume that if we can apply to an X ray tube a steady and uniform voltage, we will obtain cathode rays of which all the electrons fly at the same speed and which will therefore produce X rays of one wave length only, and that thereby we would, in fact, have complete control of the quality of the X ray beam and could alter it at will Unfortunately the matter is not so simple, and in practice we are provided with mixtures of wave lengths or, as they have been called, heterogeneous beams There are two reasons for this

X rays are a result of collisions between electrons of the cathode stream and atoms of the anticathode A head on collision after which the electron stops dead, having been robbed of all its energy, produces the shortest possible wave length A glancing collision in which the electron parts with some of its energy but then proceeds on its path with diminished speed, produces a longer wave length At the next collision it may part with the rest of its energy, or else again glance off and lose only a portion of the remanent energy A wave length longer than that due to a dead stop in the first instance results Thus we get a mixture of waves of every conceivable length from the shortest or boundary wave length to those which are too long to penetrate the glass We get, in fact, a beam of X rays of mixed wave length, which is comparable to white light and which, with suitable appliances, can be resolved into a continuous spectrum of components, just as white light shows a spectrum of colours when passed through a prism

A moment's reflection will tell us, and is confirmed by probability calculations, that there are only a few head on dead stop collisions Considering all the other types of collision in which a part only of the electronic energy is converted into radiation, and the electron flies on at reduced speed, we find that their number increases as the quantity of energy absorbed in collision decreases, till a maximum is reached After this the number again decreases and ultimately vanishes The amount of energy absorbed per collision is a measure of the wave length of X rays produced, and upon the number of each kind of collision depends the intensity of each wave length Thus, even if the voltage at the ends of the tube could be maintained at a constant value, the resulting X rays would not be of uniform wave length, i e, *the rays from a tube cannot possibly be made homogeneous in the physical sense*

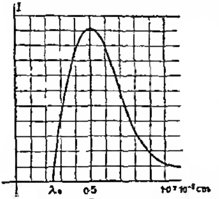


Fig 71

We can, then, draw a curve in which we show the intensity (I) of the rays on the vertical scale against the wave-length on the horizontal and it looks like Fig 71, beginning sharply

at the shortest wave length λ_o which is due to head-on collisions of electrons From there the intensity rises rapidly to a maximum value at the wave length which is produced by that type of atom-electron collision which occurs most often—and then it dies away

The second cause which tends to produce heterogeneous rather than homogeneous X rays is the variable nature of the tension With the exception of the condenser and the three phase transformer units, our X ray machinery produces voltages which rise from zero or thereabouts to a maximum and fall back to zero again This means the production of every conceivable wave length of ray, from the long one due to the voltage which can just force current through the tube, down to the shortest one obtained when the peak or maximum voltage is being applied

One would expect that such variable voltages would cause all kinds of mixtures of X ray wave lengths, and that the composition of each mixture would depend on the way in which the voltage varies, i e, on the kind of voltage curve produced by the electrical plant This is not so because the intensity of the X ray beam is proportional to the square of the voltage When the tension drops slightly below the peak the intensity of the rays drops very rapidly In other words the lower values of the voltage contribute only slightly to the intensity of the beam, and for practical purposes we can say that the curve of the distribution of energy throughout the X ray spectrum shown in Fig 71 holds good for all apparatus (spark coils or transformers), producing a variable tension In the case of continuous current plants the maximum value of the intensity is moved slightly towards the shortest wave length, and this fact is of considerable importance in X ray therapy

This heterogeneous beam of X rays having a continuous spectrum is the first and, for the radiologist, the most important result of the cathode stream bombardment in an X ray tube The composition of the beam is independent of the material of the anticathode and depends only on the maximum or peak voltage which is applied to the tube The boundary wave length is a measure of the peak voltage and therefore defines the composition of the beam for all apparatus The boundary wave length is therefore a physical quantity of considerable importance

CHARACTERISTIC RADIATION OF THE ANTICATHODE

The second conversion of electronic energy at the anticathode consists in the liberation of X rays which are characteristic of the atoms of which the anticathode consists Electrons of the cathode stream will collide with extra nuclear electrons of the anticathode atoms and will sometimes knock such an electron right out of its atomic system The gap which is thus produced on one of the atomic shells is filled by an electron falling into it from an outer shell In doing so it emits the rays which are characteristic of the particular jump in the particular atom (see page 58)

We find therefore that there are superposed on the continuous X ray spectrum from a tube, the lines of characteristic radiation of the anticathode metal Such a spectrum, obtained by the methods described on page 78, consists of a dark band crossed by blacker lines The band is the continuous spectrum referred to above, and the lines are the characteristic wave lengths emitted by the metal of the anticathode

In medical radiology, the characteristic radiation of the anticathode does not concern us much because its wave length is already longer (i e, it is softer) than the X rays which are generally employed Thus the X rays for tungsten correspond to a kilovoltage of 59 to 69 Moreover, though the intensity is great, the range of wave length of each line is so exceedingly small that the total effect due to these lines, on film or tissue, becomes negligible

THE TEMPERATURE RISE OF THE ANTICATHODE

The third effect of cathode ray bombardment is a rise in temperature of the anticathode to red or white heat It is due to cathode ray electrons whose energy is nearly spent, imparting the same to atomic systems as a whole and causing these to vibrate

This effect interests us only because it puts certain limitations on the use of X ray tubes and makes certain precautions necessary (see pages 4-16)

It must be noted, however, that of the energy of the cathode stream more than 99 per cent is converted into heat in the anticathode. The actual percentage which is used up in producing X rays depends on the voltage applied to the tube and on the atomic number of the anticathode metal.

Rutherford and Barnes found the following relation between voltage and the percentage of cathode-stream energy which is converted into X rays in a tungsten anticathode—

K V	48	64	96
per cent	0 118	0 193	0 274

ABSORPTION OF X RAYS

The fact that a shadow is cast on a fluorescent screen when a hand is held between it and the source of X rays shows that the intensity of the rays has been reduced Some of the radiation has disappeared in passing through the hand and therefore the fluorescence on the screen is not uniformly bright. A part of this vanished energy is "absorbed" by the matter through which the beam of rays passed, that is to say, it is converted into electrical, thermal, chemical and biological effects The rest is "scattered"

The use of X rays both as a diagnostic and as a therapeutic agent is based on this vanishing of the energy of the beam when it passes through matter For diagnostic purposes we use the rays which remain after passing through the body and which leave a record on fluorescent screen or film such that the various parts of the body cast shadows of a density depending on how much radiation energy has vanished, i e been absorbed within them For therapeutic purposes, on the other hand, we employ the vanished X ray energy, i e., the part which has been "absorbed" and converted

Only that portion of X ray energy which is absorbed will produce the physical, chemical and biological changes which make X rays so useful in medicine The rays which pass through the media unabsorbed and unchanged leave no effects noticeable to our senses

As long as the current through the tube is propelled by a comparatively low voltage (say 40 K V) the difference in luminosity of those parts of the screen which are not covered by the hand, and those which are is great, and so are the contrasts between the flesh of the fingers and the finger nails, or between the latter and the bones of the fingers When the voltage is increased the brightness of the fluorescence also increases, but the transparency of the hand increases much more rapidly, so that when about 100 kilovolts are employed the parts of the screen covered by the flesh of the hand fluoresce with a light nearly as bright as those which are not covered and the shadows of the finger nails and other fine details which were clearly visible at a lower tension have disappeared entirely (see Plate II)

This fact is certainly noticed by all soon after they begin to use X rays, but the important lesson to be learned from it, i e, that the finer details, which are so important in many cases for correct diagnosis, *can only be obtained with a certain quality of X rays* is frequently overlooked

If we hold a sheet of aluminium, 1 mm thick, behind the fluorescent screen, it will cast a shadow of about the same darkness as the flesh of a thin finger or as a layer of water 10 mm thick A second sheet of aluminium, added to the first, will increase the depth of the shadow, but will not quite double it If we hold sheets of platinum and lead 0 1 mm thick, behind the screen, the shadows will be much darker than that cast by a sheet of aluminium ten times as thick but though the sheets have the same thickness and platinum and lead have nearly the same atomic number there will be a considerable difference in the depth of the shadows That produced by the platinum (*atomic number 78, specific gravity 21 5*) *will be much darker than that produced by* the lead (atomic number 82, specific gravity 11 3)

These experiments show that the degree of reduction of intensity varies widely It depends on —

1 The tension applied to the terminals of the tube, i e, on the wave length of the X rays The greater the voltage, i e, the shorter the wave length, the smaller will become the reduction in intensity

2 The atomic number and the specific gravity The greater they are the greater will be the reduction in intensity

Calculations and experiments show that the intensity of X rays *increases with the square of the tension*, but that the "reduction of intensity" of X rays by any particular material *decreases* in proportion to a yet higher power of the tension In consequence of this an increase in tension does not produce proportionate effects in the fluorescent salts of screens the bromide of silver of photographic emulsions, or the cells of animal tissue They are smaller than we would expect, because although the higher voltage creates more X rays it shortens the wave length at the same time, thereby increasing the penetrating power and reducing the amount of radiation which is absorbed

SCATTERING OF X RAYS

X rays are "scattered" in passing through matter A narrow beam of sunlight passing through air or water is more obvious to an eye not placed in the actual path of the light when the air or water is turbid with smoke or suspended matter than when they are clean The reason is that the small particles of matter in suspension reflect or "scatter" the sunlight away from its path in all directions It is the same with X rays, but *all* media are "turbid" to them

In Fig 72 we see diagrammatically how scattered radiation arises everywhere It appears from the glass wall of the X ray tube whose focus is F The tissue T and

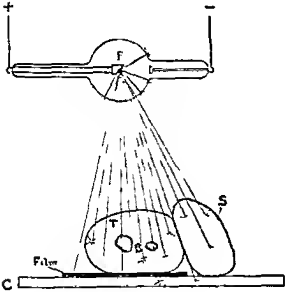


Fig 72

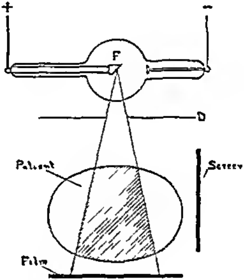


Fig 73

the bones B of the patient give rise to scattered rays, as does the sandbag S and the top of the couch C

In Fig 73 is shown a method of demonstrating the presence of scattered rays A screen is placed at the side of the patient through whom X rays pass from the focus F Although these primary rays cannot reach the screen, a bright fluorescence will be set up by scattered rays

Scattered rays tend to increase the intensity of the radiation which reaches a particular objective in the body The primary beam suffers losses through increasing distance and absorption, but that part of it which reaches the objective is increased by rays which are scattered towards this point from more distant parts of the body It was assumed for many years that just as reflected or diffused light is of the same quality as the incident beam, so scattered X rays are merely primary X rays which have been turned aside from their path That this is not so was shown by Compton

Scattered X rays are a little softer, i e, they have a slightly longer wave length than the primary beam The greater the penetrating power of the primary rays, the greater also will be that of the scattered rays, but increasing distance and absorption reduce their intensity

THE INFLUENCE OF WAVE LENGTH ON ABSORPTION AND SCATTERING

The quantity of energy which is absorbed from a beam of X rays and converted to other forms of energy grows less as the atomic number and density of the irradiated material decrease and as the wave length of the rays decreases Scattering, on the other hand, increases with decrease of atomic number and wave length

The human body consists chiefly of hydrogen, carbon, oxygen, and nitrogen, and is therefore not a heavy absorber of X radiation compared with, say, the metals

The preponderance of scattered radiation over absorbed radiation, however, increases very rapidly as the wave length decreases The relationship is best seen in a diagram (Fig 74) On the horizontal axis are plotted the wave lengths The vertical axis shows percentages of the total quantity of radiation which is removed both by *absorption* and by *scattering from the primary beam of rays* It will be seen that at a wave length of 1 0 A U 93 per cent is absorbed and 7 per cent scattered, but at 0 2 A U only 10 per cent is absorbed, whilst 90 per cent is scattered

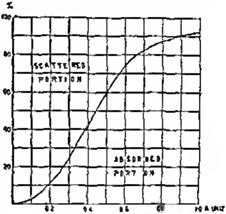


Fig 74

FILTERS

The absorption which takes place when the rays pass through matter tends to make the rays gradually more homogeneous After a beam of heterogeneous rays has traversed matter, its intensity has been weakened, but as the soft rays have been absorbed and weakened to a much larger extent than the hard ones, the composition of this beam is changed, and it now contains a higher percentage of hard rays than it did before

We use this property of matter to "filter" the X rays before they reach the human body If we use metal filters of sufficient thickness or density, the medium *and soft rays can be absorbed to such an extent that* all those rays, for instance, which would be heavily absorbed by the skin or superficial tissues are eliminated *before they reach the skin* The rays are not transformed in any way into another wave length, and it would be useless to attempt to use filters with *soft* tubes Hard rays cannot be expected below a filter unless they are generated by using high voltages The hard

rays predominate after filtration only because the soft ones have been absorbed by the filter to a much larger extent, but the hard rays become weaker too In fact, if we once more examine the intensity wave-length curve which has just been alluded to, we find that filters move the energy maximum towards the minimum wave length and decrease it at the same time (see Fig 75)

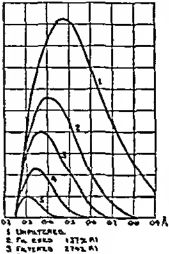


Fig 75

The degree of filtration depends on the atomic weight and specific gravity of the metal used, and on its thickness It is not possible by filtration to make the X rays homogeneous' from the physicist's point of view, but when it has been carried so far that, for instance, a 10 mm layer of tissues of the body *nearest the skin* absorbs the same percentage and no more, of the X rays which reach it as a layer of similar thickness 5 or 10 cm *below* the skin, we say that the rays have become homogeneous for *biological* purposes" (see Fig 76) To reach this degree of homogeneity for the human body, it is necessary to use aluminium filters no less than 12 mm thick, or zinc or copper filters 0 5 mm thick The latter are preferable, partly because sheets 12 mm thick become inconvenient, and partly because they scatter the rays too much

If the 0 5 mm filter of zinc or copper is replaced by one 1 mm thick the percentage of hard rays will increase 5 per cent, and the duration of the exposure has to be doubled If it were replaced by a filter 1 5 mm thick the percentage of hard rays would be increased by 10 per cent but the duration of the exposure would have to be four times as long as with the 0 5 mm filter On the other hand if a filter of 0·2 mm were substituted in place of the 0 5 mm filter the percentage of hard rays would be reduced by 4 6 per cent but the duration of the exposures could be reduced 50 per cent

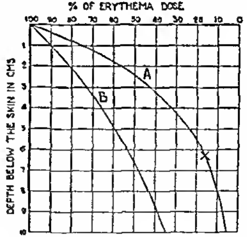


Fig 76

A represents the passage of an unfiltered beam it becomes homogeneous near X
B represents the same beam filtered through 0 5 mm copper

Filters are indispensable for all therapeutic exposures as we shall see later on Even for diagnostic exposures it is advisable to use aluminium filters 0 7 to 1 mm thick

THE CONVERSION OF X RAY ENERGY BY MATTER

What, then are the laws which govern absorption and scattering of X rays by matter? X ray energy entering a body may do one of three things (1) It may pass on unchanged, (2) It may cause a photo electron to fly out of the inner ring of an atom, at the same time causing

that atom to emit characteristic radiation as described on page 58, or (3) It may meet an electron, either alone or loosely attached to the periphery of an atom, and be scattered In that case, part of its energy is used up in setting the electron in motion, and so the energy which remains in the scattered ray is less than in the primary ray The scattered ray, therefore, has a somewhat longer wave length, i e, is softer, than the primary ray.

The discovery of this is due to A H Compton, wherefore it is referred to as the Compton effect It really means that trains of ether waves are capable of exciting a definite pressure on bodies in their path In the case of sunlight being scattered in a dust laden atmosphere, the dust particles are of such a mass that the ether wave pressure will not move them and so the energy of the ether wave is reflected *in toto* If, however, the particle is of very small mass, e g, an electron the pressure of the ether wave may be used, in part, to cause the electron to fly Its direction of flight is governed by two factors, namely (1) any forces of attraction due to atomic nuclei to which it may be subject if it happens to be an extra nuclear electron on an atomic periphery, and (2) any energy of motion which it already possesses when it meets the train of ether waves The direction in which the ether waves move after the impact with the electron, i e, the direction in which the particular electron scatters the primary ray, depends on the direction in which this electron flies after the impact Such electrons are spoken of as "recoil" or "Compton" electrons

Thus we see that as a first result of the impact of X rays on matter we get —

1 Photo electrons
2 Characteristic rays
3 Scattered rays
4 Recoil or Compton electrons

Each of these four forms of energy will now undergo a second change In the first place, a few of the photo electrons and some each of the characteristic rays and of the scattered rays will leave the body and carry on outside—from the point of view of absorption they concern us no more

Of what is left, the photo electrons will behave like cathode rays moving with every conceivable velocity up to a maximum which is determined by the wave length of the primary rays The fast moving ones will set free secondary photo electrons, accompanied as before by characteristic rays, and the slow ones will give up their energy to an atom causing it to oscillate, i e, they will produce heat

The characteristic rays which do not leave the body may give rise to photo electrons of a slow moving kind, but their number will be very small because the wave length of the characteristic rays is not sufficiently short The bulk of the characteristic rays will be scattered, giving rise to Compton electrons

The scattered portions of the primary rays which do not leave the body will behave like the primary rays in setting up photo electrons characteristic rays, scattered rays, and Compton electrons, but since the wave length of the scattered rays is longer than the primary wave length there will be fewer photo electrons and less characteristic radiation, but more scattered rays and more Compton electrons, at this second stage

Finally, the Compton electrons, being of a slow-moving kind, will, in the main, transfer their kinetic energy to an atom as a whole, causing it to oscillate or vibrate, i e, producing heat.

The second stage of absorption therefore gives us .—

1. Photo electrons.
2. Characteristic rays
3. Scattered rays
4. Compton electrons
5. Heat.

It must be noted, however, that there has been a considerable degeneration of energy The photo electrons of the second stage are slower than those of the first

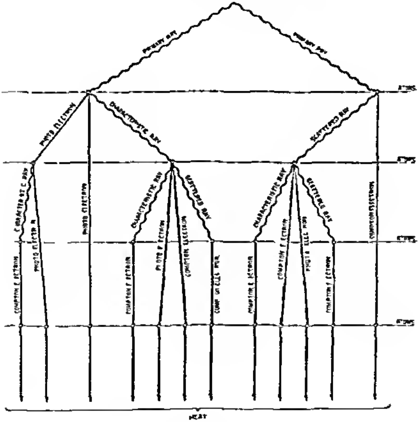


Fig 77

and much fewer in number, and the characteristic rays are of longer wave length and less intensity.

In a third stage, the same processes go on again as in the second, but less energy will leave the body as photo electrons, characteristic and scattered rays, and what is left rapidly degenerates into heat by way of Compton electrons

Fig 77 gives a diagrammatic representation of these transformations and

retransformations of energy which may be assumed to take place when X rays are absorbed by matter

The question arises whether the result of absorption of X rays is merely a heating up of the body, and, if so, why the body cannot be heated by other means to achieve the same result In answering this we must remember that though the end effect is heat, the amount of energy which is converted into heat is only a part of the total energy which was absorbed The other part is used up in producing photo electrons and in setting recoil or Compton electrons in motion These, however, are snatched out of atomic rings, and in many cases are the links which hold together complex agglomerations of atoms, in the form of organic molecules The readjustment of the equilibrium of the extra nuclear electron system after a photo electron has been removed may take time The glow of a fluorescent screen after the X rays have been stopped teaches us this and it is likely that there are atoms and molecules which continue in such an "energized" or phosphorescent condition even longer

It seems reasonable to suppose that the photographic effects of X rays on a film or their biological effects on the human body are due to the rearrangement of atoms and molecules produced by the removal of the linking electrons, but here again we must point out that other theories exist Thus Dessauer, in 1922, expressed the view that biological action is, in the main, due to the heat to which as we have seen, the absorbed X ray energy degenerates The total quantity of heat is, of course, very small, as, indeed, is the total quantity of energy of the X ray beam, but Dessauer explains his theory by assuming sudden great rises of temperature in molecular volumes He calls this the production of "point heat"

Yet another view is that owing to the removal of electrons from atomic orbits, there is a piling up of negative charges in one part of a cell and positive in another i e, the electric equilibrium of colloidal conditions is upset, thereby giving rise to photographic and biological results

Whatever be the truth it is evident that much research work has yet to be done, and the field for exploration by biochemists physicists and radiologists is a very large one

CHAPTER V

MEASUREMENTS OF X-RADIATION. DOSAGE

WHEN we wish to profit by the experiences which others have gained, or to repeat the results which we obtained previously, or to communicate them to others, it is essential that the quality and intensity of the X rays which produce certain effects can be measured and described so that the same conditions can be repeated

The effects produced by X rays either in a photographic film or in the human body depend on the amount of radiation which has been absorbed in either case

This amount of absorbed radiation is determined by —

1 The intensity of the rays Intensity is the same as that which we call "brightness" when speaking of visible light

2 The time for which the photographic film or human body is exposed to this intensity of radiation

3 The wave length or penetrating power of the X ray beam

These are the three main factors, but as intensity itself depends largely on voltage and absorption, and scattering depends on wave length, the two factors, intensity and wave length, are somewhat interlinked, and we must endeavour to separate them

MEASUREMENT OF INTENSITY

The intensity of a beam of X rays at a particular point is governed by the following four factors —

1 The intensity of rays produced at the focus of the tube, i e, the current through the tube

2 The distance between the focus and the point

3 The absorption and scattering due to matter between the focus and the point

4 Arising out of 3 the wave length of the radiation

The change of intensity of rays emitted by a tube at any particular voltage can be conveniently observed on a milliammeter, which gives us a reading of the current passing through the X ray tube

Milliammeters consist of a spool of wire suspended on jewel bearings between the pole shoes of a permanent magnet and carrying a pointer The spool is held in position by two spiral springs A current passing through it will set up a magnetic field which tends to turn the spool from its position of rest against the torsion of the springs (Fig 78) The greater the current, the greater the twist on the spool, and the

greater, therefore, the deflection of the needle over the scale, which is graduated in milliampères

A knob at the top or bottom enables us to put a certain amount of resistance in parallel with the spool whereby only a fraction—one tenth, one hundredth, etc —of the total current through the instrument passes through the spool The same deflection of the needle can therefore read three different currents according to the setting of the shunt knob A figure on this knob indicates the value of the scale reading

We must bear in mind that the milliammeter does not measure the total value of each impulse or half-cycle of current, but a mean value which is governed by the maximum value of each impulse and the number of impulses per unit of time

The position of the pointer is determined by the parallelogram of forces (Fig 79) Along A C is measured the maximum value of each impulse and along A F the time which elapses between two succeeding impulses, i e, during which no current flows in the milliammeter *Fifty intense discharges per second produce the same deflection of the pointer as* 100 *discharges of half the intensity* It is a decided advantage that this is so, because 50 intense flashes of X rays produce the same biological or chemical effects as 100 flashes of half the

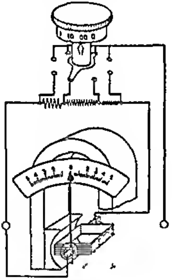


Fig 78

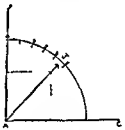


Fig 79

intensity If the milliammeters were to indicate the maximum of each single discharge, without regard to frequency, as for instance the oscilloscope tubes do, it would become necessary to measure the *number* of discharges also

This would be a slight additional complication in the case of alternating current supplies and transformer units, for we have the choice between non rectified currents at 50 half cycles per second, rectified ones at 100 half cycles, three phase ones at 300 impulses per second, and condenser units giving continuous current In the older types of high tension unit with the spark coil, the complication becomes almost insuperable, because every interrupter has a different frequency. As the milliammeters indicate a mean value, we have only to measure the current registered, the time for which it is flowing and the voltage which is driving it

One factor, however, does have a bearing on the value of the milliammeter reading and requires attention, and that is the shape of the curve of the secondary

current. On page 62 we described how the energy distribution throughout the spectrum of an X-ray beam, i.e., its quality, is practically constant for all forms of secondary current curve because the X ray intensity varies as the square of the voltage and therefore falls away very rapidly when the tension drops below peak value. This very fact, however, causes the X ray value of the milliampère to vary between one type of apparatus and another

The old spark coil, which produces steep impulses in which the bulk of the energy goes through at peak tension, converted a larger part of the electron energy of the cathode stream into useful X rays than does the transformer, which supplies an alternating current Here the voltage rises comparatively slowly to a peak, so that, particularly in the case of hot cathode tubes, where no ionization potential is necessary, many electrons fly at speeds which do not lead to the production of useful X rays Though no rays are generated, yet the current has flowed and the milliammeter has registered Such units, therefore, give less X ray intensity per milliampère than those producing steep impulses

It will be found that the condenser unit and the old spark coil give the best value in X ray intensity per milliampère Next comes the transformer with mechanical rectifier, and last the transformer with no rectification or with valves

The difference in efficiency of conversion of current into X rays between the first and the last of these types is probably as much as 1 3 With a spark coil 10 milliamperes will do what 30 will from an unrectified transformer—other things being equal Notwithstanding this point in favour of the coil, the transformer has become the unit of choice because the 150 per cent more milliamperes are easily produced, tubes to stand up to the current exist, and the regulation is more simple

The milliammeter reading therefore gives us a guide as to whether the X ray intensity from a tube has changed and if so, to what extent It cannot be an absolute measure of intensity, its value of X rays per milliampere varies not only with the voltage at which the current is flowing but also with the wave form of the secondary current, and it is an indirect measurement, that is to say, it is the measurement of a quantity upon which intensity depends—not of intensity itself. It is, however, a most useful guide in controlling an apparatus

Direct Observations of Intensity are also possible, and in making them we employ one or other of several properties of X rays Thus they discolour barium platino cyanide, they affect photographic emulsions, and they alter the conductivity of air by ionization The first two of these effects are employed in instruments for the absolute measurement of dose and will therefore be described under "Dosage"

The method of choice for X ray intensity measurements to day is ionization of air, and a considerable variety of instruments exists wherewith this can be done

IONIZATION MEASUREMENT OF INTENSITY

In Fig 80 we see a diagrammatic representation of the ionizing effect of a beam of X rays on air. Electrons are liberated from the atoms, leaving positively charged ions If two electrodes, insulated from each other and connected to a source of

electricity, are *inserted* in a chamber whose content of air is ionized by X rays, a current will be carried from the negative electrode to the positive, by means of the liberated electrons

This fact is the basis of all instruments which measure intensity of X rays by ionization An electroscope is charged with electricity so that the two vanes repel each other The charge of electricity is *then allowed to leak away to earth through* the air which has been ionized by X rays, and the rate at which this leak takes place is a measure of the intensity of the X ray beam

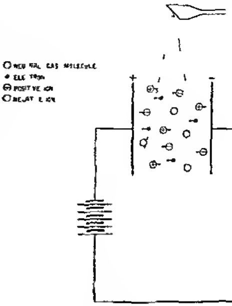


Fig 80

THE IONTOQUANTIMETER

Fig 81 shows the scheme of an iontoquantimeter A A are fixed aluminum vanes and B B are movable ones mounted on jewelled pivots To B B is attached a pointer which moves over a scale A A and B B are both connected to a wire C which passes down a tube D and ends in a stem E, inside a small aluminum thimble F The wire C and stem E are most carefully insulated from the tube D, and so is the *system of vanes A A B B from the box G which surrounds it* Both the tube D and the box G are heavily coated with sheet lead, so that only the contents of the thimble F can be exposed to X radiation

To operate the instrument a charge of electricity is given to the system of vanes A A B B by means of a small electrostatic machine, so that the movable ones B B

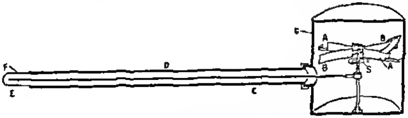


Fig 81

are caused to swing away from the fixed ones A A owing to the repelling action of electric charges of like sign The spiral spring S shown in the illustration tends to bring B B back to the zero position alongside of A A A state of equilibrium is thus set up between the repelling electric force and the restoring spiral spring force, and the pointer comes to rest somewhere on the scale, the actual position depending on the size of the electric charge

As soon as X radiation falls on the air content of thimble F, ionization is set up and the electric charge on the vane system A A B B leaks through the ionized air to the outer cover of the thimble and thence to earth The vanes therefore collapse under the force exerted by the springs, and the speed with which they do so, i e., the speed at which the pointer moves over the scale, is a measure of the ionization produced in the thimble, i e , of the intensity of the beam of X rays which causes it.

THE X-RAY-RADIUM BALANCE

Another instrument which uses the ionization produced by the X rays to measure the intensity of the beam is the radium balance designed by Professor Russ Instead of determining the degree of ionization by observing the rate at which an electrical charge leaks away from the electrometer, we balance the ionization due to the X ray beam against that which is due to a fixed radium standard incorporated in the instrument. We can then express the intensity of the X radiation in terms of a known quantity of radium

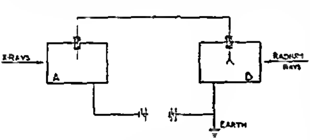


Fig 82

Two ionization chambers (Fig 82) A and B are so placed that A is exposed to X rays and B to radium rays The electroscope in B is connected by a conductor to a metal stem projecting into A Both the stem and the electroscope are very carefully insulated from their surroundings The outer walls of the two ionization chambers are connected to a source of electric supply of 200 volts continuous current, and in addition the wall of the chamber B is earthed If now A is exposed to X rays while B is unexposed, the air in A becomes ionized and the stem receives a charge from the 200 volts supply The leaves in B therefore separate When the radium is brought up to B, the air in this chamber becomes ionized and some of the charge on the electroscope can leak away The leaves therefore collapse somewhat, though not altogether, because fresh electric charge is continually reaching them from the source of supply via the ionized air in A The final position which they assume is a measure of the relationship between the ionization due to the X rays in A and that due to the radium rays in B

The Ionization Chamber is the critical part of these instruments

Fig 83.

Fig 83 shows the usual shape of such a chamber Its walls must consist of a material such that its effective atomic number is equal to that of air (7 69) If this is the case, then the ionization produced in the chamber is reasonably independent of the wave length of the X rays

MEASUREMENT OF QUALITY OR WAVE LENGTH

The quality or wave length of X rays depends directly on the voltage which is applied to the ends of the X ray tube We can therefore determine the quality by measuring either the voltage or the wave length itself

KILOVOLTAGE MEASUREMENT SPHERE SPARK GAP

The oldest way of expressing the penetrating power of X rays was by means of the equivalent spark gap This consisted of a point and a plate attached to the two discharge columns of the spark coils which were formerly used It was placed in parallel with the X ray tube (see Fig 81) At a certain distance between point and plate depending on the resistance of the tube the current would prefer to discharge through the spark gap This distance was known as the equivalent spark gap of the tube and tubes were rated at so many inches e.g

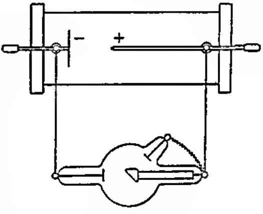


Fig 81

The equivalent spark gap fell into disuse for some years because it was inaccurate on account of the corona discharge from the point and its variability with the humidity of the air Ionization of the air by X rays also upset the spark gap readings

Latterly it has come into use again because it was found that if the point and plate are replaced by polished metallic spheres we have a spark gap whose readings are only slightly affected by humidity and other disturbing factors Careful measurements of the distance between the sphere surfaces were made and tabulated by Peek of America The table gives the length in centimetres of the spark gaps between point plate spheres 5 cm in diameter and spheres 10 cm in diameter for every 10 kilovolts from 40 to 200—i e the range covered by X ray diagnosis and therapy The point plate gap is never very accurate, whereas the sphere gap is accurate until the gap is appreciably larger than the diameter of a sphere

Crest kilovoltage	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200 kV
Point plate	5·0	7·[illegible]	9·4	11·2	13·0	15·0	17·0	19·0	21·0	23·0	25·5	27·5	30·0	32·0	34·0	36·0	38·0 cm
5 cm spheres	1·3	1·7	2·2	2·7	3·3	3·9	4·8	5·8	[illegible]	8·7	—	—	—	—	—	—	— cm
10 cm spheres	1·3	1·6	2·0	2·4	2·8	3·3	3·7	4·2	4·8	5·4	6·0	6·6	7·4	8·2	9·0	10·0	11·0 cm

Such gaps are now fitted to most high tension units and are generally so arranged that one sphere is fixed whereas the other is movable and can be pulled towards the

fixed one by means of a cord. The movable one is attached to a spring, so that it returns to maximum distance as soon as the cord is released. A pointer moves over a scale with this sphere, and the reading at which a spark passes is noted—the cord being released at the same moment.

On spark coil units such sphere gaps are essential so that the voltage can always be read at every strength of current through any tube. The complete working conditions are then known, and there is no harm in allowing the secondary discharge from a coil to pass through such a gap. *The reason for this is that the voltage of the coil drops as soon as the spark discharge has set in* (see page 27) but not before the reading of the voltage operating the tube has been obtained.

In the case of closed iron core transformers sphere gaps are also fitted but must be used very sparingly, because as soon as the discharge bridges such a gap, an arc is formed and the secondary of the transformer is practically short circuited. If this is allowed to take place too often, the transformer is subjected to severe strain.

PRE READING KILOVOLTMETER

This trouble is overcome by making use of the fact that the primary and secondary tensions of a closed iron core transformer are in the same ratio as the number of turns of wire (see page 30). This is true so long as the primary voltage is controlled by an autotransformer and not by means of ohmic resistance (see page 33) and so long as the transformer is operated within its rated output. We can then determine the secondary voltage by measuring the voltage which we apply to the primary terminals and multiplying it by the ratio of the turns.

Most closed core transformer units therefore carry a voltmeter on their control tables, which measures the primary voltage, but is calibrated in kilovolts and shows the tension available at the secondary terminals. The sphere gap which is sometimes supplied is therefore only used as a very occasional check on the kilovoltmeter and on the condition of the whole unit.

WAVE-LENGTH MEASUREMENT BY SPECTROMETER

X rays are a wave motion of the ether and have every conceivable wave length from that of γ radiation at, say, 0.01 A.U. to that of ultra violet radiation at 500 A.U. We should therefore be able to resolve them into a spectrum, just as we can form a spectrum from sunlight, by passing them through a prism or a diffraction grating.

This was impossible until von Laue had shown that crystals with their absolutely uniform arrangement of atoms would provide a natural grating in which the distance between neighbouring planes was sufficiently small to cause interference in X ray beams reflected from them. No artificial grating could be made which would have its lines so near as to have this effect.

How does the crystal grating produce the interference effect, and how can we use it to measure wave length? Fig 85 explains the phenomenon

A B, A'B', A"B", etc , are X rays which strike succeeding atomic planes in the crystal *The planes are a distance d* apart and the rays are all reflected in the direction *c*

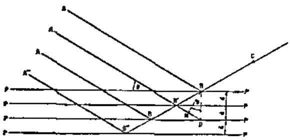


Fig 85

Considering two neighbouring rays A B C and A'B C, the former is reflected at B and the latter at B' Suppose A'B' had passed on unreflected, it would have reached the point D when the ray A B reached B

The difference in the length of path travelled by the two rays A B C and A'B'C is $A'B B - A B = A B' + B'B - A B$,

$$\text{Now } B'B = B D$$
$$A B = A'N$$
$$A'N = A'B' + B'N$$

$$\therefore\ A'B'B - A B = A'B' + B D - A'B' - B'N$$
$$= B D - B'N$$
$$= N D$$

This difference is N D $= 2d \sin \theta$ where θ is the angle of incidence of the beam

Now when this difference is equal to a whole wave length the two beams arrive at C in phase and reinforce one another, thus producing an effect on a fluorescent screen or photographic plate But when the difference is any fractional amount of a wave length, they weaken or even cancel each other and no effect is produced Radiation of a particular wave length must therefore strike the crystal at a particular angle in order that an effect may be produced on screen or film by a reflected beam C And conversely for any particular angle of incidence θ a particular wave length of X rays is picked out of the beam—if it is present at all—and reflected, thereby causing an effect on the screen or film

By *rotating the crystal with respect to the axis of the primary beam*, we vary the angle of incidence θ through every possible value, and we therefore cause every wave length which happens to be present to act on the screen or film in succession We cannot, of course, see the whole spectrum at once, because only one particular wave length is reflected at a time We can, however, take photographs of the spectrum by keeping the crystal in motion by clockwork and allowing the reflected rays to sweep over a piece of photographic film

There are two types of X ray spectrometer The first is a direct reading one by March, Staunig and Fritz, the principle of which is shown in Fig. 86

The rays pass through two slits in lead diaphragms D_1 and D_2 and through a crystal plate C The bulk of the primary goes on undeviated to strike the screen or

film S in O A portion, however, is deviated by the planes of the crystal to λ_0 on the screen or film The distance of λ_0 from O, and its position to the left or right of O, depend on the position of the crystal C

There are therefore two spectra, one on either side of O with their shortest or boundary wave lengths nearest O and the longest ones farthest away Therefore, as we rotate the crystal in either direction, the reflected ray spectrum will suddenly flash up increase in intensity as we move it farther away from O, and then die away—according to the *intensity curve on page 62* *The instrument is calibrated in such a way that* the boundary wave length can be read off directly on a scale after the two points where the edge of the spectrum lies to right and left of O have been determined

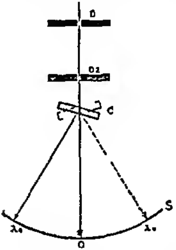


Fig 46

The position of the boundary wave length can be determined either by direct vision or photographically

The March instrument is intended chiefly for the measurement of boundary wave length and, arising out of this, the crest voltage The number of kilovolts available on the terminals of the tube can be found out, if the figure 12 4 is divided by the value of this shortest wave length If the spectrometer should, for instance, indicate this to be $\lambda_0 = 0\ 12$, the formula to find the number of kilovolts will be —

$$\frac{12\ 4}{0\ 12} = 103\ 5\ \mathrm{KV}$$

It is thus possible to find the tension prevailing *on the terminals of the tube while a current is flowing* The value of the tension thus obtained differs from, and is more important than, that given by the equivalent spark gap The latter measures the voltage immediately before an impulse discharges—i e, on *open circuit* It cannot therefore give an absolute measure of the voltage which is actually driving current through the tube, and to calibrate the equivalent spark gaps in Angstrom units as has been done, is entirely inaccurate

When the *actual number of volts* discharging through the *tube on closed* circuit is known it becomes possible to determine the efficiency of individual spark coils or transformers much more accurately than has been possible up to now

The second spectrometer is due to Seemann and is based on the same principle but the reflection of the rays takes place at the surface of the crystal and not within it Only one spectrum is produced The crystal is rocked by clockwork and the spectrum is recorded photographically

The Seemann instrument whilst it gives an accurate measurement of boundary wave length, is mainly used to record the whole spectrum with particular reference to characteristic lines

THE "HALF VALUE DEPTH" MEASUREMENT OF QUALITY

There is yet another method of measuring and registering the quality of a beam of X rays which is due to Christen It is based on the fact that the intensity of the rays is diminished by absorption and scattering and that the degree of diminution depends on the thickness of a given material and on the quality or wave length of the X-ray beam Christen suggested that the quality of the beam should be expressed in terms of the thickness of water, aluminium, copper, or any other convenient material which would reduce the intensity of the beam to one half

The easiest way to determine the half value depth of the radiation from an X-ray tube under a particular set of conditions, is to allow the rays to fall on the ionization chamber of an iontoquantimeter and measure the time taken for the pointer to move over, say, 10 scale divisions Without any change being made in the conditions under which the tube is run or in the distances from tube to ionization chamber, etc, a series of filters of aluminium or copper are now inserted in the path of the rays between the tube and the chamber With one of these, the time of discharge of the iontoquantimeter will be found to be double what it was before, i e, the intensity has been halved The thickness of the particular filter is the half value depth

Water can also be used as filter and is particularly advantageous, because its opacity to X rays is about the same as that of the human body When we know what thickness of water will reduce the intensity to one half, we also know at what depth in the body the same reduction has taken place The water must be placed in containers whose opacity is as nearly the same as possible (bakelite, etc) and in which there are no metal screws The depth of water in such a container is adjusted until the intensity has been reduced to one half

Another method of measuring the half value depth is to use one of the chromo radiometers (Sabouraud, Holzknecht, Kienbock) described on page 82, and find what thickness of material reduces the action on the radiometer to one half Such a method, though requiring less capital outlay than is involved in the purchase of an iontoquantimeter, is less accurate and demands more time

The advantage of the half value depth determination over the measurement of voltage or boundary wave length is that it takes into account the ionizing effect of rays of all wave lengths, both when no material is in their path and when the material which reduces the intensity to one half is present This is important for although the composition of a beam of rays is much the same whether produced by spark coil or transformer, yet it changes considerably when the rays pass through matter The soft components are more readily absorbed than the hard ones, and therefore the predominating wave length in a beam of X rays is a shorter one after passage through matter, whilst the boundary wave length of course remains the same This is the basis of the action of filters (see page 67) Not only is this hardening action of passage through matter taken into account by half value depth determinations, but also the difference in the amount of scattering and especially back scattering due to hard or soft rays

Half value depth measurements are not a source of joy to the physical purist, because of the number of variable factors which may influence them The doctor,

on the other hand, must remember that the measurement of voltage and milliampere age refer to the radiation as it leaves the tube The intensity and composition of the beam reaching the body, and particularly at a depth in the body, have changed considerably owing to distance from the source, and to absorption and scattering Changes due to distance are easily calculated, but those due to absorption and scattering are best determined empirically, and this is what half value depth measurements do They are likely to become a more important method of quality designation as time goes on

DOSAGE

A dose of X rays is the quantity of energy of radiation which has been absorbed and which has therefore given rise to photographic or biological results For diagnostic purposes, tables have been drawn up which tell us what current and voltage to employ at given focus film distances and for every part of the body so that the film may absorb that dose of rays which is necessary to give a good negative (see Chapter VI)

In the therapeutic use of X rays we have to deal with doses which would blacken a film so completely that it would be useless If this were not the case, we evidently could not employ the rays diagnostically at all, for we should produce an undesirable biological effect before we had achieved the desired result on the film

Other means have therefore been devised to measure how much radiation has been absorbed by the body They fall under two headings of direct and indirect methods of dosage

Direct Methods of Dosage employ the action which X rays have on a variety of substances Thus it was early observed that barium platinocyanide, when exposed to X rays, turns from its apple green colour to a reddish brown, owing to the loss of some water of crystallization This fact is used in the chromoradiometers of Sabouraud and Holzknecht and a variety of others The two mentioned are the most important, and practically the only ones now used

Another effect which is used is the action on a photographic emulsion The silver chloride of the ordinary photographic film responds too rapidly, and therefore Kienbock employed a silver bromide paper which is acted upon sufficiently slowly to record a therapeutic dose

Lastly, the ionization instruments, which have already been mentioned for the measurement of intensity can be used to record dose

The Sabouraud Radiometer consists of a booklet in which are the pastilles of barium platinocyanide and two standard tints The first of these, known as tint A, is that of the unexposed pastille The second is the colour which the pastille assumes when it has been exposed to a dose of X rays which will cause the hairs of the body to fall out This dose is therefore known as the epilation dose, and the second colour is called tint B It has been found empirically The pastilles are not very sensitive, and to obtain the changes in colour referred to above, they must be exposed at half the distance existing between anticathode and object, so that they are subjected to four times the intensity of radiation

As this discoloration is due to dehydration, the pastilles are also sensitive to high temperature The distance between the glass wall of the tube and the pastille must therefore be at least 2 cm , otherwise the heat of the glass bulb might help to discolour them prematurely As ordinary daylight restores the original colour gradually, the pastilles have to be protected from it during the exposure, and have to be compared with the standard tint in a light which is weak in actinic rays, such for instance, as the light of an incandescent lamp The pastilles can be brought back to nearly their original colour by exposure to full daylight, but sunlight should be avoided They can be used a second, possibly even a third time, but they leave no permanent record

The Sabouraud tints give the epilation dose only , there are no fractional or multiple tints available We can, however, employ the inverse square law—to use tint B to record fractions and multiples as follows

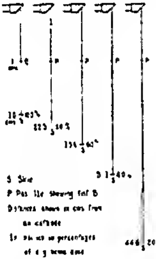


Fig 87

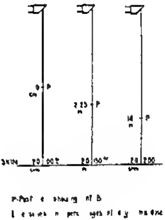


Fig 88

Fig 87 shows how *fractions* of the epilation dose can be measured with the Sabouraud pastilles, by *increasing* the distance between pastille and skin When the pastille assumes tint B, with a focus pastille distance of 10 cm the epilation dose will be reached when the *pastille skin distance* is also 10 cm , but when the latter is *increased*

from 10 to 12 3 15 8 21 6 34 6 cm
only 100 80 60 10 20 per cent

of the epilation dose will be obtained on the skin when the pastille has assumed tint B.

Fig 88 shows how *multiples* of the epilation dose can be measured with Sabouraud pastilles by *reducing the distance between pastille and skin*

The Lovibond Tintometer is a convenient accessory to the Sabouraud radio meter, as it affords a means of measuring the colour of the pastille in terms of tint B and fractions and multiples thereof In this instrument the light from an 8 c p carbon filament lamp is allowed to fall on a sheet of white paper and on

the exposed pastille The reflected light from the white paper (Fig 89) passes through a tinted glass before it reaches the eye of the observer, whereas that from the pastille reaches the eye unchanged A series of glasses can be provided, giving various tints including A (that of the unexposed pastille), B (that of a pastille exposed to the epilation dose) and fractions and multiples of B

The Holzknecht Radiometer is practically a combination of the Sabouraud radiometer and the Lovibond tintometer but equipped with a scale of its own and arranged so that the pastille can be used either at half distance between focus and skin, or else on the skin

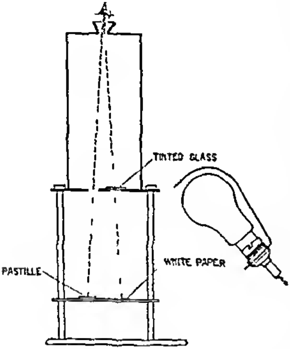


Fig 89

The pastilles are barium platinocyanide and semicircular in shape In the radiometer is fixed a piece of tinted celluloid, light at one end and dark at the other On a sliding carrier are placed an unexposed and the exposed pastille in contact, so that they form a complete circle of barium platino cyanide The unexposed pastille is covered by the tinted celluloid, and its colour seen through the celluloid is apple-green (Sabouraud tint A) at one end and red brown (Sabouraud tint B) at the other Somewhere along this celluloid strip the colours of the two pastilles will match and the dose which has been absorbed by the body can then be read on one of two scales—according to whether the pastille was at half distance or on the skin

Holzknecht devised his scale in arbitrary units H, such that 5H corresponds to Sabouraud tint B when the pastilles in each case are placed at the half distance and the radiation is unfiltered

The Kienbock Radiometer, or quantimeter measures the dose by observing the effect of X rays on silver bromide paper This is much more sensitive to X rays than barium platinocyanide

An epilation dose which changes the pastille to tint B will produce blackness on the developed bromide paper Shades of grey between the white of the unexposed strip and the black indicate fractions of an epilation dose The strips are exposed on the skin and the epilation dose is denoted by 10 *x*, and divided into ten shades *Each differs from its neighbour by 1 x Thus 10 x on the Kienbock scale is equivalent* to 1 B on the Sabouraud scale The dose which produces an erythema on the skin as distinct from the mere falling out of hair, is 12 *x* The strips have the further great advantage that they leave a permanent record and can be pasted in a case book

The black tint of 10 x on the scale is, however, not convenient, partly because there is no indication whether it has just been reached or whether it has been exceeded already, and partly because the differences between the tints of 8, 9 and 10 x are small, so that it is difficult to distinguish between them. The differences between 1 and 7 are, however, great, and it is therefore advisable to rely on these only for the tests and for comparison, and this can easily be done. It is known beforehand how long *approximately an exposure has to last*. If it is likely that with the distance, the filter and the number of milliampères used, the erythema dose will be reached in about eight minutes, the exposure should be interrupted after two minutes to develop the Kienbock strip. If it shows a tint similar to 3 x on the scale, this would mean that one fourth of the erythema dose has been given, and that if the exposure is continued under the same conditions for another six minutes, the full erythema dose will have been reached. If the tint should be similar to 4 x on the scale, the *total* exposure will have to last six minutes only. If used in this way, the exposures can be timed more accurately than if we would attempt to rely on the tints 8 to 10 for comparison.

The only disadvantage is that the results cannot be read off until the strips have been developed for a definite time (60 seconds) in a developer of definite composition and at a definite temperature (65° F). These particulars are given with each packet of strips. The trouble involved, though it is undoubtedly present, is small, and the advantage of permanent record is large.

Direct Dosage by Ionization is still in its infancy. It involves the absolute measurement of the amount of ionization produced by a beam of X rays, and not merely the degree of ionization for purposes of comparison of one beam with another as is the case in determination of intensity (page 74) and in the indirect method of dosage (page 87).

The following is the definition for the unit dose of X rays called 1 Rontgen (1 *R*).

"The absolute unit of X ray dose is that amount of X ray energy which, when irradiating 1 c.c. of air at 18° C and 760 mm mercury pressure, will cause one electrostatic unit of electricity to flow from one electrode to the other—it being understood that all the electrons due to ionization are employed, that there is no production of electrons from the walls of the ionization chamber, and that the current which is measured is at saturation point."

At the moment of writing, the whole question of the definition and measurement of the unit R, and also of the biological value which is to be assigned to it, is under discussion in an International Committee, but there can be no doubt that the absolute measurement of dose by ionization, when accomplished and made reasonably easy, will mark a great step forward in X ray therapy.

COMPARISON OF DIRECT METHODS OF DOSAGE

The chromoradiometers of Sabouraud, Holznecht, and Kienbock were invented and calibrated at a time when skin therapy only was known. Their units refer to the dose of unfiltered X rays which will cause the hairs to fall out (epilation) and

1B (Sabouraud)=5H (Holzknecht)=10x (Kienböck)

If the time of exposure is prolonged by about 20 per cent beyond any one of these doses, the inflammation and subsequent discoloration known as erythema (see page 86) will occur.

Measured in terms of the electrostatic units, the epilation dose appears to be about 600 R, but more work has yet to be done before this can be regarded as definite

Hard rays and zinc, copper or aluminium filters are now used in all forms of therapy The deeper the organ to be treated, the harder the ray and the heavier the filter This has changed the conditions for the following reasons The metal salts of the chromoradiometers, as well as the cells of the human body, are more transparent to hard rays than to soft, a smaller quantity of the former being absorbed, but the transparency of the tissues of the human body increases more rapidly than that of the metallic salts, because the latter have a greater atomic weight and specific gravity Whereas 1B or 5H or 10 x represents almost an erythema dose when soft unfiltered rays are used, these tints represent much less when hard filtered rays are employed In other words, such hard rays produce their discolouring effect on barium platinocyanide long before they cause erythema in the skin

Thus at 170 K V and with 0 5 mm copper + 1 mm Al the erythema dose on these three radiometers is roughly

$$2\tfrac{1}{2}\ B = 12\ H = 65\ x$$

Evidently, therefore, if we use any one of them to measure a dose we must always add under what conditions of voltage and filter the rays were applied Doses are only comparable when they refer to rays of the same hardness and filtration

It is claimed for the most modern ionization chamber that it responds to hard or soft rays in almost the same manner as the human body That being so, we can expect an erythema whenever 600 R as measured by a suitable ionization instrument have been applied Dosage will be a simple matter when a reliable, easily operated ionization instrument is produced in which the total dose in R can be read

ERYTHEMA DOSE

To " measure " anything we must have a well defined unit, or standard, or effect, such as a yard stick, a standard candle, or the boiling point of water The generally recognized unit for the biological effects produced by X rays is the erythema, and the dose of radiation which produces it is the unit skin dose (U S D or, in German literature, HED)

The first evidence of the erythema is a redness of the skin appearing one week after exposure This colour changes within three weeks to brown, and leaves a permanent bronzing of the skin *

This unit is fairly accurate in so far that the latitude in the dose required to produce just this effect is not very great. When the dose is too small, no *permanent*

* Unfortunately, some latitude is possible because one operator may consider a pale redness and bronzing another a darker red and brown colour to be the " erythema. Attempts have been made to introduce standard colours but they have not yet led to a satisfactory result.

It is worth noting too that the French understand under an erythema a radio epidermitis, or destruction of the epidermis with re-epidermatization following within three weeks. The Germans regard this to be an X ray burn of the second degree The exposure required to produce this French erythema is fully three times as long as that required to produce what the Germans regard to be an erythema.

discoloration will follow, when it is too great, blisters will appear and the skin peel off, or, if the duration of the exposure has been exceeded to a larger extent, a serious burn with ulcerations will follow Numerous experiments and actual exposures have proved that when the skin of the *same part of the body* is exposed, the difference in the reaction of grown up patients does not exceed 15 per cent The skin of the neck and shoulder is the most sensitive Next follows the skin of the abdomen, then that of the upper legs and the back, whilst the skin of the face is the least sensitive Light haired patients are about 10 per cent more sensitive than dark haired ones, and only patients suffering from tuberculosis, diabetes, exophthalmic goitre, nephritis, or syphilis make an exception and are more sensitive The part of a patient's skin which has already been exposed to the X rays also remains more sensitive for a few weeks or even months than a skin which has not yet been exposed

The erythema dose as a unit is, however, rather inconvenient, because it takes such a long time till the results show whether the exposure was just right to produce an erythema or whether it was too long or too short It is also insufficient, because it shows only the intensity of the rays which prevailed *on* the skin, but does not indicate the intensity of the rays which penetrated to objects 6 or 10 cm *below* the skin It is therefore necessary to employ electrical or chemical quantimeters which enable us to determine the dose during the exposure on the skin, or at various depths below it

INDIRECT DOSAGE

This is based on the consideration that if two beams of X rays of the same composition are allowed to fall on the human body under the same conditions of filter, focus skin distance, size of irradiated field on the body, etc —that is, if quality and intensity of the beams are identical when they reach the body, and if scattering within the body is also the same—then they will produce exactly comparable biological effects in equal times

The variable factors are —

1 The kilovoltage
2 The milliamperage
3 The focus skin distance
4 The size of the irradiated field
5 The filter
6 The frequency of the secondary impulses

Having produced an erythema with a certain tube in a certain time, and with certain values assigned to each of these six variables we can reproduce the same degree of erythema with the same tube, in the same time, if the six variables have the same values

It is evident that the focus skin distance, the size of irradiated field, and the filter can easily be given the same value Moreover, the frequency of secondary impulses, where the apparatus is not a condenser plant, giving practically continuous

current, is very generally 50 or 100 per second and does not vary This does not apply to the spark coil and interrupter unit, to which we will refer directly.

There remains, therefore, the voltage and milliampèrage These are constant if the primary voltage is constant. If it varies, then the voltage also varies and in the same ratio Moreover, if the primary voltage varies, then the heating current in the cathode spiral is changed, and with it the milliampèrage

A careful watch on the pre reading kilovoltmeter and on the milliammeter is all that is necessary, and when these vary they must be brought to their initial settings by adjusting the controls A nurse can easily learn to do this, and the use of a stabilizing device (page 35) ensures a constant heating current and milliampèrage, which is even more important than the absolute constancy of voltage

In regard to spark coil units, it should be noted that, where these work from alternating current, the frequency of impulse in the secondary is quite constant When a continuous current main is employed and is subject to fluctuations, the frequency will vary with varying primary voltage In such a case, then, it is necessary to have a speed counting device which registers the number of revolutions per minute of the interrupter and which may be either mechanical or electrical The actual speed of the interrupter is, of course, best regulated by a resistance in the motor circuit.

The milliampèrage is controlled by means of the filament heating current, and is read on the milliammeter

The voltage from spark coils, on the other hand, cannot be read on a pre reading kilovoltmeter, but must be observed by means of the sphere spark gap and adjusted by the coarse and fine controls on the switchboard Both operations can be carried out while the tube is working

Having assured the constancy of the six variable factors mentioned above, we can rely on producing the same effect on the human body (neglecting for the moment any idiosyncrasy thereof, see page 139) if we use the same apparatus and the same tube But various apparatus and various tubes produce the same result in varying times This difference is due to the fact that the percentage of hard rays emitted varies somewhat with the individual apparatus used, for reasons which have been explained Even tubes from the same firm and of the same construction may vary slightly This last difficulty is overcome in the following way

Instead of measuring dose in electrostatic units, which is difficult, or in terms of barium platinocyanide discoloration, the biological equivalent of which varies with penetrating power, we determine in what time our apparatus and tube will produce an erythema dose under certain conditions of the six variables How this can be done is described in the chapter on therapeutic applications on page 140

Having found this time for the erythema dose, with a given tube under certain conditions, it is best to put the tube aside and use it only as a standard wherewith to compare other tubes, when they are bought. It sounds an expensive way of doing things, but it certainly pays in the long run, in accuracy of work

Every time a new tube is bought, it must first be "calibrated" by being compared with the standard one This can be done in various ways The best is to employ an iontoquantimeter and compare the intensities of the X ray beams from the

two tubes under exactly similar conditions Bearing in mind that dose is the product of intensity multiplied by time, we see that if the two tubes cause the pointer of the electrometer to move over the same number of scale divisions, in the same time, they will also each produce erythema in the same time If, however, the times in which the pointer moves across the same number of scale divisions are different, then the times necessary to produce erythema are in proportion to these iontoquantimeter discharge times And as we know the time required by the standard tube, we can readily calculate the time in which the new tube will produce erythema, without going to the trouble once more of measuring it

We can, however, use chromoradiometers for this purpose of comparison, just as well, since their discoloration is proportional to the intensity so long as the quality (kilovoltage) of the rays was the same in each case Pastilles or bromide strips must be exposed to the standard tube, until they reach a fractional tint, say ½ B on the Lovibond tintometer, 3 H on the Holzknecht scale, or 6 x on the Kienbock scale—because these fractional doses are more easy to estimate accurately with the suitable instruments than the full doses Then the time taken by the new tube to achieve the same dose under the same conditions is measured and once again the ratio of these times gives the time necessary for erythema

PERCENTAGE DEPTH DOSE'

The beam of X rays decreases in intensity as it penetrates deeper and deeper into the body This is partly due to increasing distance and partly to absorption and scattering The decrease due to distance can easily be calculated That due to absorption might also be calculated, but the mathematics involved are more complicated That due to scattering, however, is practically beyond calculation and, as we shall see, scattering increases the intensity at a depth rather than decreases it

It is therefore best to find out empirically what change has been wrought in the intensity owing to all three causes acting together The intensity at a given point inside the body, under a given set of working conditions, is measured and is expressed as a percentage of the intensity at the surface The result is known as the percentage depth dose

It is of great importance that this percentage should be as large as possible, for the greater it is, the smaller will be the dose of X rays which the skin and overlying tissue and blood, etc , absorb before organs at a depth, such as the ovaries cervix, lungs, etc , have received the dose which is intended for them

The percentage depth dose depends on —

1 **The Quality of the Radiation** The greater the penetrating power of the rays, and the greater the degree of homogeneity of the beam (see page 68) the smaller will be the reduction of intensity by overlying tissue If the rays are soft, or if the beam has some hard and much soft radiation (inhomogeneous), then the overlying tissue will absorb much

2 **The Distance between Anticathode and Skin** The greater this is, the smaller will be the difference between the intensity at the surface and at a depth In Fig 90 we see this distance to be 25 cm in one case and 50 cm in the other Assuming an intensity of 100 at the skin surface in either case, we can readily calculate, from the law of inverse squares, what the intensity at other points in either case will be And we find that a point 10 cm below the skin (say for instance the uterus) will receive an intensity of 51 in the first case and 69 in the second These are the percentage depth doses in either case, and it is evident that the second one is the better, for it subjects the overlying tissue to less radiation by the time that a certain total dose is achieved 10 cm down It would therefore be an advantage to use large distances in all cases, but this obviously necessitates either a larger output from the tube or a longer time of exposure There is therefore a limit to the focus skin distance

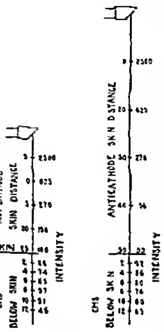
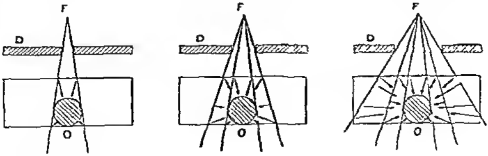


Fig 90

3 **The Area of the Window on the Skin** This determines the size of the cone of rays in the body X rays in passing through matter are scattered in all directions (see page 66) The irradiated cone of the body will therefore scatter rays outwards and also inwards Reference to Fig 91 shows us that a small organ deep down in the body will experience a greater intensity of the X rays at the point where it is situated, if the cone is large, than if it is small

The percentage depth dose is therefore increased if we employ as large a window



F focus D=diaphragm O object

Fig 91

on the skin as possible With very hard rays, and a diaphragm with an aperture of 18 × 18 cm, the influence of the scattered rays may cause the dose reaching a uterus

to be nearly 3 times as large as it would be with primary rays only after making allowance for the losses due to increasing distance and absorption

It should be noted that when we increase the focus skin distance whilst leaving the window on the skin the same size we decrease the volume of the irradiated cone In Fig 92 the truncated cone *a b c d* encloses a greater volume than *a b e f* With reduced volume the quantity of scattered radiation becomes smaller and this diminution would neutralize any gain which an increase in focus skin distance would otherwise produce in the percentage depth dose We must therefore increase the size of the skin window when we increase the focus skin distance

4 **The Distance of the Object to be Treated Below the Skin** The greater this is the more is the intensity affected by absorption and scattering due to overlying tissue

The factors 2 3 and 4 are linear measurements of which 2 and 3 are easily found whilst 4 is given by knowledge of the exact position of the object The first factor is given by the sphere gap or the spectrometer and the size of the filter Even so the percentage depth dose cannot be calculated because the effects of absorption and scattering are far too complicated It can however be determined by means of a *phantom* This must consist of material which has practically the same average atomic number the same density and therefore the same opacity to X rays as the human body Water absorbs only 5 per cent less than a mixture of muscles and fat and therefore fulfils this condition well A mixture of 20 per cent of beeswax and 80 per cent of paraffin serves equally well and is easier to handle Chambers to contain water or slabs of the wax of a variety of thicknesses are required

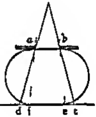


Fig 92

Measurements are now made of the intensity of the beam of X rays at the surface and at the required depth within this phantom

The iontoquantimeter is provided with wax and water phantoms and is not only the most convenient instrument for the purpose but also the best because of the fact that its readings vary with the wave length of X rays in the same way as human tissue If an iontoquantimeter is not available one of the chromoradiometers can be employed but it must be borne in mind that the beam of X rays in passing through the phantom is being changed in its composition as the softer rays are filtered out The pastille or the bromide strip will register a greater intensity than is biologically present

If an iontoquantimeter is available the rate of discharge of the electroscope is observed when the ionization chamber is exposed to the direct influence of the filtered X rays at a distance of say 50 cm from the anticathode and when it is at say 60 cm from the anticathode and a tank of water 10 cm thick is interposed between the filter and the chamber Two water tanks should be employed and they should be made of ebonite but there must be no metal as this would generate secondary rays and influence the result

In the first case, the ionization chamber would be in front of both of them, being, as it were, on the skin In the second case, it would be between them, that is to say, 10 cm below the skin Thus, the scattered radiation due to a body which is approximately 20 cm thick would be reproduced The intensity of the rays is inversely proportional to the time of discharge of the electroscope, and so the ratio of these two observed times gives us the ratio of the depth dose to the surface dose

EXPERIMENTS WITH THE PHANTOM

The percentage depth dose is best measured with an iontoquantimeter as described above, but if such a one is not available, we can obtain an estimate of the depth dose with very reasonable accuracy by using silver bromide paper as follows

The phantom should consist of slabs of wax, and the silver bromide paper must be cut in strips and inserted in light tight envelopes, like Kienbock quantimeter strips

The strips are arranged so that six of them are on the surface of the phantom, and one each at 6, 8, and 10 cm below the surface

The kilovoltage, milliampérage, focus skin distance, filter, and skin window must be arranged as in actual therapy

As we know, from the experiences of others, that at 200 K.V, 4 M A, 23 cm focus skin distance, and a filter of 0 5 mm Cu + 8 mm Al, we get the erythema dose in about 30 minutes, it is best to make this test with an exposure of, say, 20 minutes

When it has lasted 2 minutes it is stopped and one of the strips on the surface is withdrawn The second is withdrawn after it has received a total exposure of 3 minutes, the third after 4 the fourth after 6, the fifth after 8, the sixth after 10 minutes The exposure is then continued *till* a total of 20 minutes has been reached, after this the strips exposed at the various depths below the surface are withdrawn too The latter can be marked with the figures 6, 8, and 10 cm, to indicate the respective depths in cm at which they were exposed, those on the surface may be marked with the figures 10, 15, 20 30, 40, and 50 per cent, to indicate the percentage of the total exposure which they received

They are then developed simultaneously, fixed and washed, and when they are dry the tints are compared If the tint of the strip which was exposed at 8 cm depth is similar to the tint of the strip which was withdrawn after 4 minutes' exposure, this would show that the dose prevailing at a depth of 8 cm was 20 per cent of the dose which reached the surface If it shows a tint similar to the strip which was withdrawn after 3 minutes, the dose prevailing at the depth of 8 cm would have been only 15 per cent of the surface dose

The strips are then pasted in a case book, or on a card as used for card indexes, ten strips and the necessary text require a card not less than about 5 × 8 inches The text should run somewhat as follows —

TUBE No 1	*Sept 6th*, 1928
Primary current	220 volts
Secondary current	4 M A
,, voltage	200 K V
Filter ..	0 5 mm Cu + 3 mm Al
Aperture of diaphragm	6 × 8 cm
Focus skin distance	23 cm
Exposure .	20 minutes
Percentage depth dose	
6 cm	per cent of surface dose
8 cm	,, ,, ,,
10 cm	,, ,, ,,

To gain more experience, and to secure greater accuracy, it is well to repeat the experiment, and this time to withdraw the strips on the surface after 3, 5, 7, 9, and 12, or 15 minutes, thus obtaining more, and intermediate tints, as control Otherwise we proceed as explained in Experiment No 1

With *new* tubes it is wise to make another trial exposure after they have been used for about 6 hours Good tubes can then be used for 100 to 150 hours without risk of a change taking place in them, but they should be tested after that time once more Some 500 hours' work can be got out of good gas or Coolidge tubes Each tube should receive a number and a card on which the cases for which it was used are entered.

CHAPTER VI

THE PRACTICAL APPLICATION OF X RAYS IN DIAGNOSIS

The successful application of X rays in diagnostic problems depends on the knowledge of a number of simple physical phenomena and on the excellence and design of the accessory apparatus which must be employed.

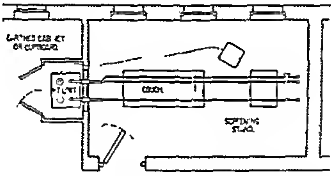


Fig 93

The X-ray Room —Both the high tension unit and the couch or screening stand on which the patient is examined are large pieces of furniture The X ray

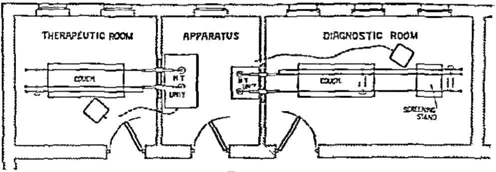


Fig 94

room must therefore be of adequate dimensions The best plan is to place the high tension unit in an adjacent room or cupboard by itself and to bring the high tension

leads through large insulators in the wall to the room in which the diagnostic apparatus and controlling gear are placed Such a plan is shown in Fig 93 It can be elaborated as in Fig 94, where there are two generating units in the machine room one feeding the diagnostic room and the other the therapeutic room In such cases the machine room should not be less than, say, 8 feet by 12 feet and 11 feet high and should be fitted with a door which, when opened, automatically cuts off the main supply from the generating units The two rooms for diagnosis and therapy should be not less than, say, 13 feet by 16 feet and 11 feet high

In those cases—and they are the majority—where the high tension plant is in the room in which it is used, the latter should be not less than, say, 15 feet by 17 feet and 11 feet high

All therapeutic and diagnostic rooms must be well lit and ventilated, and those in which screening is to be undertaken must be capable of being darkened

The Complete X-ray Pavilion—In very large hospitals it frequently happens nowadays that a separate building is erected to house radiology The design of such a special department is of course governed by such considerations as available space and money, the number of patients to be dealt with, etc In Fig 95 we see the plan of a one storey building giving a first rough idea of how a radiological department can be laid out

It will be noticed that diagnosis and therapy are separated, the former being in the left wing and the latter in the right wing of the building A central waiting room separates the two wings

Apart from rooms for doctors and nurses, there is in this diagnostic wing a general clinical examination room Adjoining this are the fluoroscopic (screen) and radiographic rooms, which are separated from each other by the transformer room In this the units which feed both rooms can be housed

Facing the doors of the flouroscopic and radiographic rooms are a series of cubicles in which patients can undress and be prepared for X ray examination

The dark room is large and is entered by a maze or light trap from the radio graphic room Special traps can be provided in the wall so that charged cassettes can be handed straight into the radiographic room Such traps are a very convenient addition Needless to say, the walls of the dark room must be ray proof

The remaining two rooms in the diagnostic wing are for dental radiography, and for the viewing recording and storing of films

On the therapeutic side, there are again the rooms for doctors and nurses Adjoining these is a room in which the records of patients are registered and kept Next comes a clinical examination room, and next to this is a room marked "Calculation," in which charts and computations of depth doses, etc, can be made and kept

There is the same system of patients' dressing cubicles, from which they can reach the deep therapy and superficial therapy rooms The transformers are placed in a separate room between the two therapy rooms, and in front is the operator s cabin, carefully protected from X rays and with lead glass windows through which the patients can be observed.

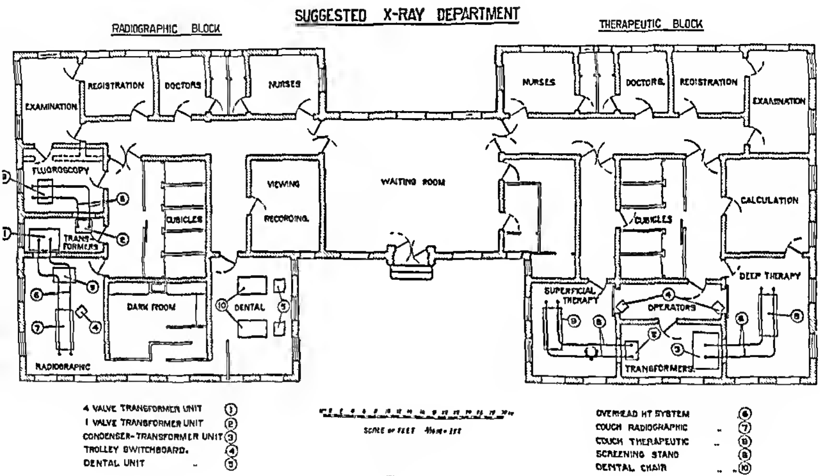

SUGGESTED X-RAY DEPARTMENT
RADIOGRAPHIC BLOCK
THERAPEUTIC BLOCK
EXAMINATION
REGISTRATION
DOCTORS
NURSES
FLUOROSCOPY
TRANS-FORMERS
CUBICLES
VIEWING
RECORDING
WAITING ROOM
DARK ROOM
DENTAL
RADIOGRAPHIC
NURSES
DOCTORS
REGISTRATION
EXAMINATION
CALCULATION
CUBICLES
DEEP THERAPY
SUPERFICIAL THERAPY
OPERATORS
TRANSFORMERS
4 VALVE TRANSFORMER UNIT (1)
1 VALVE TRANSFORMER UNIT (2)
CONDENSER-TRANSFORMER UNIT (3)
TROLLEY SWITCHBOARD. (4)
DENTAL UNIT .. (5)
SCALE OF FEET
OVERHEAD HT SYSTEM (6)
COUCH RADIOGRAPHIC .. (7)
COUCH THERAPEUTIC .. (8)
SCREENING STAND (9)
DENTAL CHAIR .. .. (10)

Fig. 95.

Two spaces at the side of the waiting room can serve for a door keeper's office and as a store, or possibly to house a staircase to a basement, etc

When the requirements are known both as regards the nature and quantity of the work to be done, the general plans in any particular case can assume shape The remarks above may perhaps be a slight guide as to what can be done

Coronaless Overhead Gear—Great care must be exercised in arranging how the high-tension current is brought to the X ray tube This current is very dangerous to human life—particularly nowadays when powerful high tension transformers are employed Every possible precaution is therefore necessary to prevent contact between operating staff or patient and the high-tension leads This is achieved by fixing conductors across the room at a height of not less than 9 feet from the ground The high tension is fed into these and taken from them by spring reels with heavily insulated cable to the tube

High-tension currents spray in the form of corona from all sharp points or corners Corona causes the oxygen and nitrogen of the air to combine and produce nitric oxide, thereby fouling the air of the room and corroding all metal parts To avoid this, the overhead conductors are made of metal tubing not less than ½ inch in diameter, and all open ends are finished off with metallic spheres

Overhead High-tension Switches—In a department in which more than one X ray tube is in use, say, in a *screening stand*, and over and *under a couch it is an* obvious disadvantage fraught with some danger, if the high tension leads from the transformer must be changed over from one tube to another whenever a change from screening stand to couch, etc , is necessary This is obviated by the use of an overhead coronaless high tension switch in which two discs of insulating material (see Fig 96) carry a number of contacts A spindle, which can be rotated by pulling a cord carries two moving arms which bring the high tension and filament currents to the various contacts on the discs In this way the current can easily and safely be directed to any one of the various X ray tubes in the department (see Fig 97)

Shock-proof Apparatus—It has long been the aim of engineers to produce apparatus in which the danger of high tension shock is eliminated by making it quite impossible for the patient or the operator to touch any part which is not at earth potential Some tubes and plants have been designed in which either the tube is encased in an earthed metallic shield and the current is brought in through wires enclosed in earthed shields, or else both the tube and the transformer are housed together in an earthed tank The trouble with such apparatus is that the output *of X radiation is rather limited where shock proof tubes are used and the plant* becomes unwieldy where tube and transformer are moved together A better way is to shock proof a whole department by putting the transformer in a room by itself and leading the high tension current to the tube in cables enclosed by earthed covers The tubes themselves are arranged in earthed guards of such dimensions that the output of radiation is not interfered with

This second course has the advantage that any tube may be used, any current and tension may be employed the easy movement of the tube is not hampered, and the whole installation is much less costly

Screening Stands, Couches, Tube Stands—The function of these is to bring the tube, the patient, and the fluorescent screen or photographic film easily and rapidly into such position that the necessary examination can be made They must satisfy two main conditions First, they must be so constructed that the risk of patient or operator coming in contact with high tension is reduced to a minimum To this end all couches and screening stands should receive the high tension current at a point some 7 feet above the ground, whence it should be brought in insulating tubing to a point quite close to the tube Moreover all such apparatus should be carefully earthed so that any high tension discharge into the metal parts is led away to earth at once.

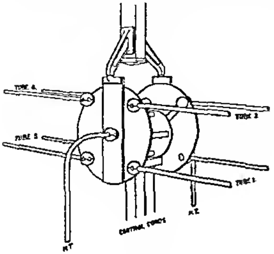


Fig 96

Secondly, all couches and stands must be so made that the operating staff are not exposed to primary or scattered radiation This point is dealt with in the chapter on ' Protection " (pages 161 167)

Apart from these two considerations the question of these diagnostic apparatuses is one of design and mechanical skill Here as in other machinery, it will be

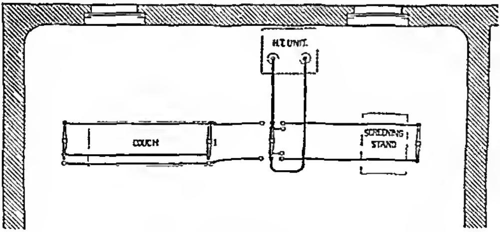


Fig 97

found on the whole that that which is simplest and most robust is generally preferable to that which is equipped with all manner of auxiliary gadgets to serve a variety of purposes but to specialize for none

Diaphragms.—The primary radiation from the tube must be confined within certain limits X rays act like an irritant poison, and the patient must not be

exposed to a greater dose than is absolutely necessary for the diagnostic or therapeutic purpose to be achieved Moreover, the operator must under no circumstances be exposed to the primary beam

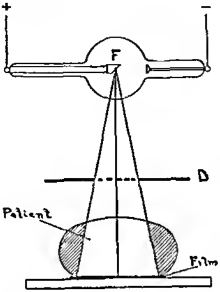


Fig 98

Flat diaphragms which consist of lead sheets with circular holes or, preferably, with rectangular holes of adjustable size, are used so that the fluorescent screen or

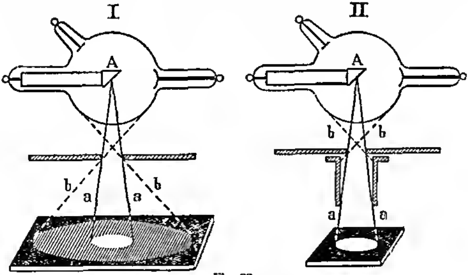


Fig. 99.

the photographic film is just fully covered and no more (Fig 98), or that the cone of primary rays just includes the part of the body to be treated.

Scattered rays must be eliminated as much as possible in diagnostic work because they cause a uniform blackening of the film and obliteration of all fine detail.

We must distinguish between the scattered rays coming from sources between the focus of the tube and the patient, especially those from the glass walls of the tube and the rays which are scattered by the body of the patient.

The former are best dealt with by a cylinder diaphragm Fig 99 shows how such a cylinder of lead glass or of metal covered with lead will eliminate the rays which come from the glass walls and which cause a large half shadow (penumbra) round the central illuminated spot The rays scattered by the patient's body are removed by a Potter Bucky diaphragm

Potter-Bucky Diaphragm —This consists of strips of lead built up between

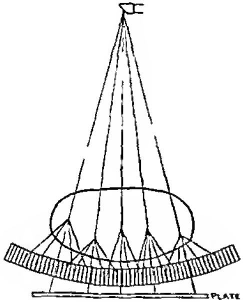


Fig 100

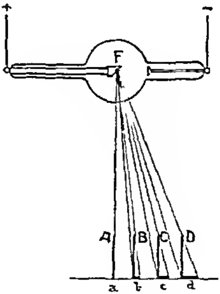


Fig 101

strips of wood or wax in such a way that they are radial to the rays The lead strips thus cut off a small portion only of the rays which come direct from the anticathode, but they cut off entirely the rays which are scattered by the body (Fig 100) The grid in which the lead and wood strips are mounted is kept moving uniformly so that no shadows of the strips are cast

Centring the Tubes —The tube should be so placed that a line which joins the centre of the film or fluorescent screen to the focus of the tube is at right angles to the axis of the latter

Rays which strike the object and film obliquely will cause some distortion as is apparent from Fig 101

There are various ways of centring tubes In the case of the old gas tube or

the universal Coolidge tube, both of which are housed in a protected box, it is sufficiently accurate to insert a cylinder diaphragm of very small diameter (Fig 102A) in the usual place on the front of the tube box and observe the effect on a fluorescent screen If the focus of the anticathode is properly centred, an even circle will appear on the fluorescent screen When the focus is out of centre, the illuminated patch ceases to be a circle and becomes distorted

In the case of self protected tubes a telescopic pointer can be screwed to the front of the tube (Fig 102B) to show the direction of the central ray

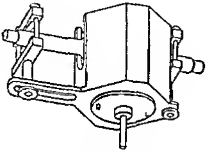


Fig 102A

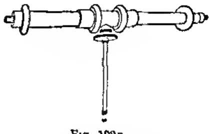


Fig 102B

Aluminium Filters for Protection during Diagnostic Exposures —In diagnostic work, the protection of the operators is more important than that of the patients because the former may have to make several exposures in the course of a week, whereas most patients are exposed for less than a couple of minutes, but they require protection too While being examined on a fluorescent screen, the patients are frequently brought quite close to the tube so that the intensity of the rays reaching the skin is great, and these examinations occasionally last a considerable time If a negative has to be made of the thicker parts of the body, especially the abdomen, the number of M.A seconds required is great too, and an exposure may have to be repeated It must be remembered that with unfiltered rays of medium penetrating power an erythema is produced in a few minutes *One third* of the erythema dose is sufficient to produce sterilization of the ovaries, and as the testicles are close to the skin, the spermatozoa are sure to be injured in a very short time Men run the risk of being sterilized if exposures near the abdomen are made without a filter and special protection of the testicles

It is therefore strongly recommended to use aluminium filters for *all* diagnostic exposures, at any rate for all examinations on a fluorescent screen and for all those exposures on a plate which aggregate to more than 200 M A seconds The quantity of X rays which passes through tissues of the human body 10 cm thick will be weakened by only 10 per cent if an aluminium filter 0 5 mm thick is placed between tube and skin, or by 18 per cent if an aluminium filter 1 mm thick is used In other words, with objects 10 cm thick, the number of M A seconds used has to be increased by no more than 10 to 18 per cent to make up for the loss by absorption taking place in aluminium filters 0 5 to 1 mm thick The number of kilovolts does not alter these

figures perceptibly, but they vary somewhat with the thickness of the tissues which the X rays have to traverse

On the other hand, the protection offered by these filters is great They absorb almost entirely the very softest rays, which are of no use whatever for diagnostic examinations because they do not penetrate farther than 1 or 2 mm below the skin, and cannot reach the fluorescent screen or photographic film. We can, however, give *twice* the number of M.A seconds when we use a 0 5 mm aluminium filter, and *four times* as much when we use 1 mm filters before we need fear the injury which would be produced without one of these filters

Fluorescent Screens consist of finely divided crystals of barium platinocyanide (green) or zinc sulphide (white) spread evenly on cardboard surfaces The barium salt is seldom used now owing to expense and because the white salt is at least as bright and sharp in detail The important point about such screens apart from brightness is that they must fluoresce and not phosphoresce The light which they give must cease as soon as the exciting X rays cease If this is not so there will be blurring of outlines when we examine moving organs such as the heart, duodenum etc

Most patients are examined first on the fluorescent screen In a few cases this alone will give sufficient information, so that no exposure will be required on a film In the majority of cases, subsequent exposures on a film will be desirable, partly to obtain a permanent record and partly because a good negative shows more details than the eye can discover on a screen Even if it is certain that a negative has to be made, a previous examination on the screen is desirable, because the area which should appear on the negative, and the position of the patient which will show the injuries best, can thus be found out It is advisable to use higher tension for screening than for radiography, because the intensity of the rays increases with the square of the voltage Moreover, it is wise to have an adjustable rectangular diaphragm available and also a grid This latter is practically a stationary Potter Bucky diaphragm It of course casts shadows of its lead strips, but they are thin and do not disturb the picture much when one is accustomed to them On the other hand, the presence of the grid greatly adds to the definition and contrast of the image on the screen

The examination should not begin until four minutes after the ordinary day or electric light has been excluded, to allow the pupils of the eyes to dilate The room must be perfectly dark, and care must be taken that all light from incandescent filaments of X ray tubes or valves is excluded

Intensifying Screens —A very important accessory to X ray photographic technique is the intensifying screen, which is a means of converting X ray energy into visible light and then allowing this rather than the X rays themselves to act on the sensitive emulsions of the film The screens consist of a foundation of cardboard or cellulose on which is spread a layer of finely divided crystals of calcium tungstate These absorb the X ray energy which falls on them and light up like a fluorescent screen

The photographic film is more sensitive to visible light than to X rays because it absorbs the former to a much greater extent than the latter By placing such

intensifying screens in close contact with the emulsion, we cause the fluorescence to act rather than the X rays and we obtain more effect on the film for the same quantity of X ray energy emitted from the tube—we "intensify" the effect of the rays

Intensifying screens enable us to reduce the duration of an exposure to about one eighth of the time which would be required without them To use them is therefore a great saving in the lifetime of the tubes and enables us to finish many difficult exposures in so short a time that it is easy for the patient to keep still and hold his breath Apart from these advantages, the screens have valuable effect on the degree of contrast between the various shadows on the film (see page 127)

In modern X ray practice, where films with two sensitive surfaces (see page 111) are employed, two screens are used This does not double the intensifying effect because some 60 per cent of the incident energy is absorbed in the top screen and the emulsion still further weakens what is left, so that the second screen cannot be reached by more than about 30 per cent Moreover, the beam has been filtered through the first screen and the emulsion, and therefore contains a greater proportion of hard rays which are less easily absorbed by the second screen The fluorescence and intensifying effect of the second screen is therefore not more than one third or one quarter that of the first The value of the two screens lies in the increase in contrast

Cassettes—Great care must be taken that there is no air space and no matter between the surfaces of the screens and the emulsion of the film On the one hand, good cassettes with spring backs to exert pressure on the screens and film must be used, and on the other, the surface of the screen must be kept scrupulously clean An air space between screen and film produces a blurred patch, whilst dirt or markings on the screen show similar marks on the negative

The screen should not be larger than the film, otherwise the sharp edges of the latter leave marks on the screen which would show on every negative made subsequently It is therefore necessary to have separate screens for all the various sizes of films

Screens require delicate handling They are best left in the cassette in which they are used All screens of good quality are washable and can be cleaned with a swab of cotton wool steeped in water or in a weak solution of soap and water

CORRECT EXPOSURE

The standardizing of the dark room technique (see pages 111–125) gives us films which are perfect from the chemical point of view That is to say, that all particles of the silver bromide which have been energized are reduced, and non energized ones are left alone to be dissolved by the fixing solution The important condition for success from a radiographic point of view is, however, that the correct number of silver bromide particles have been energized—in other words, that the exposure was right as regards time and quality (penetrating power) of the radiation

There is no entirely easy method of arriving at the correct exposure, and experience must necessarily play a considerable part The factors, apart from the

quality of the photographic material, which chiefly affect the exposure time are —

1 Strength of current
2 Distance from tube focus to film
3 Thickness and nature of object.
4 Penetrating power of the radiation (i e kilovoltage)
5 Whether or not intensifying screens and Potter Bucky diaphragm are being used

Exposure indicators which do not allow for every one of these factors are useless, and tables which do make all the necessary allowances and corrections must be used with care and knowledge

The following table gives the number of seconds of exposure which are necessary for various parts of the body at various voltages when —

1 We use a hot cathode and one milliampere of current.
2 The current is obtained from a closed core transformer with or without rectifier
3 The distance from tube focus to film is 26 inches, i e, that which is used for Potter Bucky work
4 The patient is a normal adult of about 12 stone weight
5 Two intensifying screens are employed
6 No Potter Bucky diaphragm is used

EXPOSURE TABLE

Peak kilovoltage	50	55	60	70	85	100	110
Head (back to front)	—	—	—	—	40	81	27
Head (lateral)	—	—	—	36	21	17	14
Teeth	14	8	6	—	—	—	—
Spine (cervical)	—	—	34	18	11	8	—
Shoulder	—	—	25	15	8	0	—
Elbow	—	29	19	11	8	4	—
Wrist	21	13	8	5	—	—	—
Hand	16	12	6	4	—	—	—
Fingers	8	6	—	—	—	—	—
Lungs	31	18	13	8	4	2	—
Stomach (meal)	—	—	30	17	10	7	0
Spine (dorsal)	—	—	—	30	17	12	11
,, (lateral)	—	—	—	—	36	27	23
Kidney, Gall bladder	—	—	—	40	25	18	16
Spine (lumbar) Pelvis	—	—	—	—	30	21	18
Knee Joint	—	—	21	13	8	0	4
Leg	—	21	15	8	5	3	—
Ankle, Foot	26	16	10	6	4	—	—

CORRECTIONS IN THE EXPOSURE TABLE FOR ALTERED CONDITIONS

1. **Strength of Current.**—The effect of X rays on a film, i.e., the quantity absorbed, at any particular voltage, may be taken as proportional to the product of intensity and time of exposure :—

$$D = I\,t$$

where D is the quantity or dose absorbed, I the intensity and t the time. If, therefore, we double the intensity, i.e., the current to which it is directly proportional, other things being equal, we must halve the time, and so on.

For visible light, however, the equation is not so simple. It becomes

$$D = I\,t^p$$

where p is a fraction. In other words, if we double the intensity, the time becomes less than half.

Since we use visible light rather than X rays when we employ intensifying screens we must pay attention to this fact. The value of p is about 0.8.

In making allowance for alteration of current when we use the exposure table, we must therefore remember that as we increase the current we will obtain over exposure if we apply the formula :—

$$D = I\,t$$

and the degree of over exposure will become the greater, the more we increase the current.

It follows from this that it is all to our advantage in trying to get short exposures if we make the current as large as we possibly can.

2. **Distance from Tube-focus to Film.**—The time given in the table must be divided by the square of 26 and multiplied by the square of the new distance. Thus if the distance is to be altered from 26 to 20 inches, the time x seconds becomes

$$x\,\frac{20^2}{26^2} = 0.6x.$$

3. **Thickness and Nature of Object.**—Alterations in this factor call for the greatest amount of experience. *It is best to reduce or increase the time of exposure* rather than to alter the kilovoltage on the tube.

4. The table gives a choice of kilovoltages for all parts of the body. The kilovoltage which is selected depends on the amount of current which the apparatus can give. If the available current is very large, i.e., if the plant is a big one, it is wise to select as low a kilovoltage as possible. If, however, the output is limited, then the kilovoltage must be increased.

5. The table is calculated on the assumption that two intensifying screens are used. If no screens are to be used, each of the times given must be multiplied by eight.

6. When the Potter Bucky diaphragm is used, each time given in the table must be multiplied by 4 for kilovoltages below 70, and by 3 above.

Example 1 —What is the time of exposure for a pelvis, when 40 M A at 85 K.V are used with two screens and a Potter Bucky diaphragm ?

Answer $30 \div 40 \times 3 = 2\ 25$, i e, $2\frac{1}{4}$ seconds

Example 2 —What is the time of exposure for teeth when 10 M A at 50 K V are used ? No screens and a focus film distance of 13 inches

Answer $14 \div 10 \times 8 \times \frac{13^2}{26^2} = 2\ 8$ i e, 3 seconds

The Patient —It is necessary that the part of the body to be examined should be naked, to avoid the shadows of buttons, clothes, etc, and that it should be *as near as possible to the film* If, for instance, a negative of the *right* shoulder or hip joint has to be made it is necessary to raise the *left* side considerably, so that the right side presses on the film, if the kidneys have to be taken, it is desirable to raise the knees and the upper part of the body, that the spine may become convex, so that no air space is left between it and the film.

It is necessary that the patients should rest comfortably so that they can easily keep quiet A good negative cannot be obtained unless the part to be taken keeps motionless during the exposure Small pillows or cushions, suitable rests for arms, legs, etc will frequently help the patients to remain quiet in the desired position

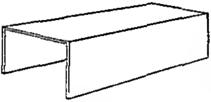


Fig 103

Fig 103 shows a simple wooden tunnel arrangement which permits of a lateral view of the knee being taken from above The tunnel is placed over one leg of the patient and the other leg is placed on the top, with the film situated between the top of the wooden structure and the patient s leg

If the abdominal region has to be examined, it is necessary that the patient should begin to take aperients some forty-eight hours before the exposure is made The bowels must be empty and no solid food should be taken on the morning when the exposure is made

Frequently it is necessary to paste small coins or pellets, with adhesive plaster, on to the nipples, the umbilicus etc, so that they appear as landmarks on the negative, and allow the distance to be measured which some object has from a well-defined spot

Compression —To keep the part to be examined motionless, and partly also to reduce its thickness, compression is frequently used A stout canvas band can be stretched across the patient, and sacks filled with sand can be attached on either side, or better, it can be stretched with the help of a roller and lever as tight as the patient can stand it, and can be fixed in this position with a clamp (Fig 104) Cylinder diaphragms attached to the boxes enclosing the tubes are also very convenient, for they can be pressed into the body

Some Hints for More Difficult Exposures —A large number of exposures for the arms, legs, shoulders, heart etc are so easy that most beginners succeed in obtaining fair and useful negatives at the first attempt. The chief difficulty is to

place the patient and his limbs and the tube in such a position that the organs we wish to examine are well within the central rays emanating from the anticathode and above the centre of the film, and to see that the patient does not move during the exposure

When the lungs have to be examined for the first signs of tuberculosis, an exposure on a film is necessary, because the fluorescent screen does not show as many fine details as a good negative will do The film should be on the chest, and the tube behind the back. If the tube were in front, the shoulder blades and the ribs, which are closer together at the back than at the front, would obstruct too much Moreover, the lungs are nearer the front surface, and can be brought closer to the film when the latter is on the chest It is much easier for the patient to keep motionless if he can fold his arms round the cassette and the stand holding it, than when the arms have to hang down to be out of the way The exposure has to be made during deep inspiration, and the patients have to be instructed and exercised in this a few times before the exposure is made

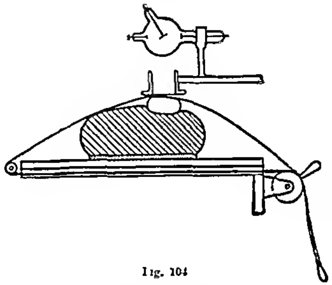


Fig. 104

There are, however, a fair number of difficult exposures, for which long and large experience is indispensable X rays of suitable wave length must be employed (see page 127) When this condition is fulfilled, it becomes possible to show stones in the kidney weighing about half a gram! The chemical composition of the stones, however, has an influence too Stones consisting of uric acid are not easy to detect with X rays, because their specific gravity is the same as that of the surrounding tissues They occur in the bladder, and even large stones, which are clearly visible with the cystoscope, throw faint shadows only on the negative Stones consisting of *pure* xanthin or cystin are invisible too, and for this reason it may happen that a stone exists, though even a technically perfect negative shows no trace of it Experience has shown, however, that about 98 per cent of all stones in the kidneys, and 75 per cent of all stones in the bladder, will show All the stones found in the kidneys and ureters usually contain some lime, and this has a greater specific gravity and makes them visible Stones containing oxalate or phosphates are also clearly visible Phleboliths and some calcifications of glands may cause slight shadows, which may be mistaken for stones

To make the alimentary tract visible, a meal of *chemically pure* sulphate of

barium should be taken This is not only safer, but also cheaper, than the preparations of bismuth which were used for some time for this purpose It is, however, important that it should be pure It should be quite free from barium chloride, which is a violent poison, and also from barium carbonate, because the latter, though not poisonous *itself, may be converted into a chloride by the* hydrochloric acid of the stomach Pure barium sulphate is a fine *white* powder It is non toxic on account of its insolubility Danger arises only when it is adulterated by other soluble barium salts

The following is a good recipe which has been used regularly for many years in a large number of hospitals 150 grammes of sulphate of barium, 20 grammes Mondamine (Maizena flour), 15 grammes cocoa, 10 grammes sugar, and 400 c.c water *This mash should be taken while warm*, *when cold it is too* thick or lumpy to fill the finer cavities or folds of the alimentary tract.

Several preparations, such as Rontyum, exist in which barium sulphate is *supplied ready mixed with a colloidal substance which keeps it in suspension for nearly* two hours, and with sugar or vanilla, etc, to give it a pleasant taste. The addition of a colloid is necessary to prevent the barium salt from forming a sediment at once and so *giving rise to faulty diagnosis*

If the patient takes such an opaque meal, and the exposure is made on a film after he has swallowed all or the greater part of it, nothing but the outlines of the stomach will be visible on the negative This will reveal deformities, or unusual positions of the stomach, but in most cases it will give little or no information about a suspected beginning of a growth, or ulcer, etc Much more can be learned if the patient is made to *drink* the meal *while he is being examined on a fluorescent screen* Much depends then on a suitable consistency of the meal If too thin, it will pass too quickly through the stomach and will deposit a sediment. The meal should have the consistency of a thick cream, so that it is still possible to drink it. Any irregular shape of the interior of the stomach, or an obstacle preventing the even expansion of the meal, will thus be revealed while the meal is entering the stomach, and if anything suspicious is noticed, the screen should be replaced by the cassette containing the film and the exposure can thus be made at the correct time, while the irregularity is noticeable Pure sulphate of barium when mixed with Mondamine or mashed potatoes, etc, has the consistency of porridge and is too thick for this purpose When mixed with milk only, a thick, stiff sediment will begin to form as soon as the stirring has ceased

The ureters are not visible, but to find out whether a stone is in the ureter or outside a catheter, opaque to X rays, can be introduced first and the shadows then indicate the exact position of ureter and stone The gases in the bowels are transparent, and cause dark spots on the negative which may be misleading The aperient helps somewhat, but a plain convex Luffa sponge, or an inflated rubber ball or cushion, may be pressed into the region of the abdomen to be examined, to disperse any gas bubbles (see Fig 104)

If an exposure of the left kidney is being made, part of the spine, or of the lower ribs, should be visible on the plate, as a criterion The appearance of the bones will show whether the penetrating power used, the duration of the exposure, and the development have been correct. As soft rays have to be used, the vertebræ of the

first film has been exposed, we move it to a distance of 8 cm. on the other side, and when the film has been changed, make the second exposure. The plane in which the tube is to be moved must be parallel to the plane of the film, so that the distance between the anticathode and the film is the same in both instances. The direction in which the tube is moved must be rectangular to the longest side of the object; if we take an elbow, for instance, the tube must be moved across, not parallel with, the arm

Large films are examined in stereoscopes with reflecting mirrors, or else reductions of the films can be examined in ordinary stereoscopes.

CHAPTER VII

FILM TECHNIQUE

In the obituary notice of a prominent London radiologist it was stated that his success in radiography was in a large measure, due to the great personal care which he bestowed on the purely photographic side of his work. It is certain that careful technique in the X ray room is frequently spoilt by lack of attention to some simple detail in the dark room.

In the following pages I have endeavoured to put forward the advantages of standardization of the photographic process. This involves careful attention to certain details, after which the dark room work becomes practically automatic, and the gain is that the radiologist can spend his time and energy on attending to the patient, the exposure, and the correct interpretation of the result.

I am indebted to Professor Eggert, Dr Peterson, Dr Francke and others for much help obtained in studying their writings.

The Photographic Material consists of an emulsion sensitive to light and X rays, which is uniformly spread in a layer of gelatine on both sides of a sheet of celluloid or on one side of a glass plate. The former is known as the X ray double film, and also by a variety of trade names and the latter as an X ray plate. The double film is a comparatively recent invention, and up to its coming the use of the plate was universal. The advantages of the film however are so great that plates will vanish from X ray work altogether as time goes on. Films—

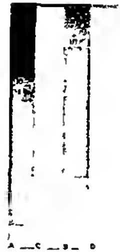
1. Occupy one sixth the space of plates
2. Weigh only one tenth as much as plates
3. Are unbreakable
4. Have certain very definite photographic advantages

The first three points make films easier to store and to send about the country.

THE PHOTOGRAPHIC PROCESS

The sensitive emulsions of a film consist of silver bromide in gelatine. When exposed to radiation (either X rays or visible light) the particles of silver bromide absorb energy—they are "energized," and in this condition they are easily reduced to metallic silver, which forms a black and opaque deposit when the film is immersed in a suitable reducing agent. The quantity of silver which is thus deposited depends on the amount of radiation which was absorbed by the film. When all the energized particles have been reduced, the film is transferred to a solution of sodium

PLATE III



makes of films, is to place them in double envelopes or in cassettes, as usual, and to cover them over entirely with a sheet of lead 2 mm thick. This is then drawn back one centimetre, and an exposure is made for, say, one tenth of a second (or any other convenient time). Then the lead is drawn back another centimetre and X rays are again turned on for the same time, and so on. Plate III shows such a comparison in which A C are strips of double film and B D are plates, A and B being respectively with and C and D without, accelerating screens. The experiments were made with a Coolidge tube, 1·5 M.A. 52 kilovolts, 30 in. focus film distance, and one tenth second exposure per step. Agfa double coated films and one of the best of modern X ray plates were used. The pictures are negative, and therefore the lower end has received least, the top end most, radiation. The three conditions mentioned above are satisfied as follows:—

1. The strip showing the greatest blackening in its lightest space is the one which gives the greatest response to the smallest amount of X rays, and it is evidently A, the double film with two screens.

2. The increase in density from one step to the next is different in each of the four strips. In A the increase per step is considerable and can be observed for every step. A shows much contrast both in the transparent and the dense parts of the negative. In B the main increase per step is at the lower end and the denser steps at the top show little contrast. C and D do not show very great contrasts from step to step at any point.

3. The greatest density is produced at the top of A.

Scientific use is made of such strips by measuring the actual density of each step on a photometer and drawing a curve for each strip in which the densities are plotted on a vertical axis and the time of exposure (logarithms for the sake of convenience) on the horizontal axis.

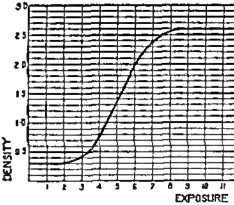


Fig 106

In Fig. 106 we see the general form which such a curve will take. Starting horizontally it will, at a certain value for the time of exposure, rise more or less steeply till at a greater length of exposure it again becomes horizontal. The initial horizontal piece is due to the fact that development should always be carried so far (see below) that unexposed silver bromide just commences to be reduced to silver—a condition which is indicated by the presence of the smallest perceptible density of fog on the unexposed parts of the film. The upper horizontal piece represents the maximum density which can be reached when all the silver salt is reduced to metallic silver, and prolongation of the exposure, no matter for how long, will not increase it.

The inclined part of the curve is the piece which interests us from a radiographic

point of view It is known as the "gradation" of the film or plate, and in Fig 107 we have the curves corresponding to the film and plate experiment shown on Plate III

We observe, first, that when the gradation is steep as in curve A, Fig 107, and strip A, Plate III, slight variations in exposure (and therefore also in intensity of X rays) will produce large differences of density, whereas a film with flat gradation (curve C and strip C) requires larger differences of exposure or intensity to produce perceptible changes of density

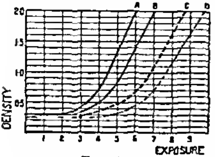


Fig 107

Secondly, we note that the steep ascent of the curve of the densest strip, i e, the one which was most sensitive to X rays (strip A, Plate III, and curve A, Fig 107), occurs after less exposure, and is therefore nearer to the vertical axis than are any of the other curves The position of the steep piece with respect to the vertical axis is therefore a measure of the sensitivity

And, finally, the use of intensifying screens makes the gradation of the film or plate curve steeper, and moves the ascending piece towards the vertical axis.

It becomes evident that the film with the steepest gradation and with the gradation curve nearest the vertical axis, is the most suitable for X ray work

The film must be exposed for such a time that the medium densities (half lights) in the picture are situated about half way up the steep part of the curve Then a variation of intensity of rays will produce densities above or below the medium one, but still situated on the steep bit. Any other exposure would put the lighter or darker parts of the film on the lower or the upper horizontal piece of the curve In the first case there would be no contrast at all, but just uniform transparency in the thickest parts of the body, and in the second the thin parts would all be uniformly black and indistinguishable

Up to this point we have considered variations of quantity or intensity of X rays and have tacitly assumed that the quality or penetrating power has remained constant This, however, depends on the kilovoltage which is applied to the tube The higher the voltage the shorter is the wave-length of the emitted radiation. Long wave rays (soft) are more heavily absorbed both by the body and by the bromide of silver than short ones (hard) Hard rays produce little contrast and a flat picture, whereas soft rays give much contrast and a brilliant negative Given the same quality of radiation, the double film with steep gradation will always show more contrast than a film with flat gradation, or than a plate The double film with steep gradation can therefore be used with harder rays than a flat gradation film or plate and still give a diagnosable picture Now the intensity of the emitted X rays is proportional to the square of the kilovoltage, and therefore the film which, due to its steep gradation, can be used with harder rays, requires considerably shorter exposures, without detriment to the quality of the picture Undoubtedly harder rays also produce more scattered radiation, and this gives rise to fog, but on the other hand scattered rays are generally eliminated by means of a Potter Bucky diaphragm

DEVELOPMENT

Developers vary one from another in their behaviour, and so the choice of the particular solution to be used depends partly on the condition obtaining during exposure and partly on the demands which the finished negative has to satisfy

In radiography these conditions and demands are more simple and straightforward than in ordinary photography The intensity of the beam of X rays, coupled with the thickness of the object which they have to traverse corresponds to the degree of illumination in ordinary photography, and the variation of the opacity to X rays between one part of the object and another is the radiographic counterpart of the high light and low light contrast of landscape or portrait work The X ray film has to deal with smaller differences of ray intensity as a result of this variation of opacity than the ordinary photographic film or plate On the other hand we have the advantage in radiography of being able to increase or decrease the amount of radiation at will by altering the milliampèrage in the tube, and we can make more or less contrast by changing the kilovoltage and, therefore, the penetrating power

In ordinary photography we allow for too much or too little illumination or contrast of an object by choosing a suitable emulsion and a suitable developer In radiography, however, we can correct the corresponding points by our apparatus controls and, if we have chosen the conditions correctly, the task of the developer is nothing more than to convert all the energized particles of silver bromide into black metallic silver The developing process is complete as soon as those particles of silver bromide which have not been energized by X rays, and which consequently respond only slowly to the developer, commence to be reduced This would cause that deposition of metallic silver throughout the whole emulsion which we call fog and which would ever increase in density till at last no bromide is left

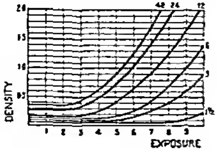
The developer which must be regarded as the most suitable—assuming that the times of exposure are correct—is the one which produces the greatest possible transparency in the unexposed parts of the finished picture, whilst at the same time giving the largest degree of contrast

The number of developers which have been found suitable in radiography is small and three only are of importance They are Glycin Rodinal and Metol Hydroquinone Of these, the Glycin solution as purchased from dealers, is diluted to 1 in 4, the Rodinal solution to 1 in 10 whereas Metol Hydroquinone is supplied in dry form and made up as stated on the tin

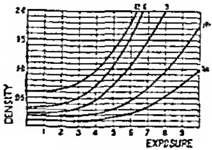
We can examine how these three developers compare as regards contrast and transparency by exposing a film in steps as explained on page 113, and then cutting it into strips which we immerse in the developer under test. We remove one strip after ¾ minute, another after 1½ minutes, and others after 3 6 12, 24 minutes respectively After they have been fixed and dried, the strips are measured up photometrically and density curves are prepared In Fig 108 we see such groups of curves for the three developers in question and the figure which appears against each curve shows the number of minutes for which the particular strip was immersed in developer

We assume that the best possible result is produced when the film has been

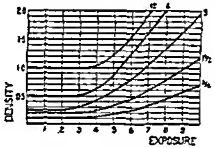
developed up to the point when the silver bromide, which has not been acted upon by X rays, commences to be reduced This point is reached when the unexposed step on the film, i e, the lightest one, shows a density due to fog, which is just perceptible. On the particular photometric scale which was used this is about 0 25



Glycin



Metol Hydroquinone.



Rodinal.

Fig 108

On the group of curves relating to Glycin we see that the one corresponding to 12 minute immersion has a density value for its horizontal piece of 0 15 The 24-minute curve has 0 28 A curve commencing at the permissible 0 25 would therefore correspond, say, to a 22 minute immersion.

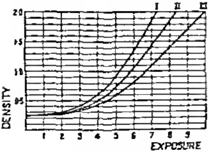


Fig 109

Similarly for Metol Hydroquinone a 5 minute immersion curve, and for Rodinal a 3 minute immersion curve, would commence with a fog density value of 0 25

We see also for each of these three developers that longer immersion increases the fog density Metol Hydroquinone gives 0 32 for a 6 minute and 0 6 for a 12 minute immersion. Rodinal gives 0 5 for a 6 minute and 1·0 for 12 minute immersions, and Glycin, which is the best developer in this respect, gives only 0 38 fog density after as much as 48 minutes' immersion. In other words, over-development causes fog rapidly with Rodinal, less so with Metol Hydroquinone, and least with Glycin.

If next we determine the density curves of these developers at the optimum immersion times (i e , to give a fog density of not more than 0 25), and plot these curves on one diagram (Fig 109), we see that the Metol Hydroquinone curve (I) has the steepest gradation, that the Glycin curve (II) is flatter, and the Rodinal one (III) flattest of all

We can therefore conclude that, provided we adhere strictly to and do not exceed the optimum time of development (5 minutes), the Metol Hydroquinone developer is not only quick and therefore time saving in its action, but is the one which gives the best contrasts and therefore the best detail

EFFECT OF TEMPERATURE

All the sensitometric tests referred to above have been made at the same temperature, namely 18° Centigrade (65° Fahrenheit) Temperature, however, has a considerable effect on the speed of development, and moreover it affects different developers to a varying extent The resulting change in the optimum time of immersion has been studied, again by the sensitometric method, and is shown in Fig 110 The optimum immersion times are plotted vertically, and the corresponding temperatures horizontally

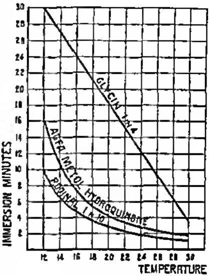


Fig 110

We can summarize the result in the following table —

	12°	14°	16°	18°	20°	22°	24°	Centigrade
Metol Hydroquinone	16	10	7	5	4	3½	8	Minutes
Glycin 1 4	30	27	24	21	18	15	12	
Rodinal 1 10	10	6	4½	3½	3	2½	2	„

From this we see that using Metol Hydroquinone on a cold winter s day at a temperature of, say, 12° Centigrade (59° Fahrenheit) we must immerse for sixteen minutes to get the same result as we would get in five minutes at 18° Centigrade (65° Fahrenheit) *Now 12° Centigrade is a comparatively high temperature for* winter time developer, but the curve shows that if we drop below this the optimum time increases very rapidly—in fact, we reach the point where no amount of immersion will produce development The correct temperature of the developer is of very great importance In our latitudes, where for the greater part of the year too low a temperature prevails, the necessary heat is best produced electrically

THE DEVELOPING SOLUTIONS

The three developers mentioned above are put on the market in a form ready for use—the Metol Hydroquinone being a powder which is supplied in quantities sufficient to make 8 oz or ½, 1, or 2 gallons of solution, whereas

Glycin and Rodinal are solutions which have to be diluted to 1 4 and 1 10 respectively

The Metol Hydroquinone developer can also be made up from the constituent chemicals according to the following formula

3	grammes	Metol
90	,,	Anhydrous sodium sulphite (or 180 grammes crystalline)
7	,,	Hydroquinone
50	,	Potassium carbonate
5	,,	Potassium bromide

These chemicals are dissolved *in the order in which they appear above*, in 800 cubic centimetres of tepid (preferably distilled) water The solution is then made up to one litre and employed undiluted

One charge of this solution of 2 gallons in the developer tank is not exhausted till about twelve dozen 12×15 in double-coated films have been developed

THE FIXING SOLUTION

This may consist either of a concentrated solution of sodium hyposulphite* diluted to 1 in 4, or better, of a so-called acid fixing bath This can be bought as a powder ready mixed in tins containing enough to make ½, 1, or 2 gallons of solution, or else it may be made up according to the following formula —

30	grammes	Potassium metabisulphite
250	,,	Sodium hyposulphite
1000	c c.	Water

This solution, which must not be diluted, is durable. It need not be renewed every day, as is the case with the plain hyposulphite solution mentioned above One charge of 2 gallons to the fixing tank will fix about six dozen 15×12 in double-coated films When development is complete, the films must be carefully rinsed *before they are immersed in the fixing bath* *No daylight must enter during fixation* because any exposure before the silver bromide has been completely dissolved produces a yellow or reddish fog The last remnants of silver bromide are slow in dissolving in the fixing solution, and so *it is well to prolong the fixing process for some minutes* after the last visible traces of the silver salt have disappeared The fixing process takes ten to fifteen minutes when the solution is kept at 18° Centigrade (65° Fahrenheit)

In summer, and particularly in hot countries, the temperature of the fixing bath frequently rises too high, and as a result the gelatine becomes soft and may even float away from the glass or celluloid support. Under such circumstances it is wise

* The term hyposulphite is incorrect. The salt which is employed is sodium thiosulphate —but by common usage this has always been known as sodium hyposulphite, or briefly "hypo."

to use a solution containing alum to harden the emulsion, and a fixing bath made to the following formula will be found best —

1000	c.c.	Water
200	grammes	Crystalline sodium hyposulphite
60	,,	,, ,, sulphite
60	,,	,, chrome alum
10	,,	30 per cent acetic acid

The fixing bath must be kept scrupulously clean from every kind of contamination, particularly from traces of developer

RECOVERY OF SILVER FROM FIXING BATH

We have seen above that the process of fixing an X ray film consists in dissolving the unreduced silver bromide by means of sodium thiosulphate (commonly known as sodium hyposulphite) There is produced silver thiosulphate in solution which becomes more and more concentrated In large X ray departments it is well worth while for the sake of economy to recover the silver from this fixing bath more especially since it can be done very cheaply

The method consists in adding a solution of sodium sulphide to the fixing bath, whereby silver sulphide is precipitated It is convenient to employ four Winchester quart bottles, as these will accommodate the two gallons of fixing bath which form one charge of the fixing tank When such a charge is exhausted and must be replaced, the old solution is filled into the four bottles so that there is approximately the same amount in each Eighty grammes of sodium sulphide are now dissolved in as small a quantity of water as possible, and one fourth of the solution is added to each Winchester quart. A black precipitate of silver sulphide is formed and the bottle must be shaken to ensure that as much precipitate as possible is formed The bottle is then allowed to stand overnight. In the morning the precipitate will have sunk to the bottom and is covered by a clear yellow liquid If this has not happened, enough sodium sulphide was not added Whether the supervening liquid is clear or not, a few drops of the concentrated sodium sulphide solution should once more be added to make sure that all the silver is now present as silver sulphide When all the precipitate has collected at the bottom of the bottle, the clear liquid is decanted and the precipitate is filtered off from the remainder The filtrate is then dried and sold to one of the firms who make a speciality of recovering precious metals

THE DARK-ROOM

The first rule in all dark room work is absolute cleanliness, and one of the main contributing factors towards this end is sufficient space It is essential that the operators, whether there be one or more, should have enough elbow room in working and should, in particular, have enough table space A fruitful source of trouble is when the charging of cassettes with unexposed films and intensifying screens has to

take place on the same table as developing and fixing, or when, as is too often the case, the developing dishes, etc, have actually to be moved away to make room for the filling of cassettes In large departments it is advisable to have a separate room for loading and unloading, and in small ones there should at least be a separate table for the purpose —far removed from dishes, tanks and sinks, so as to prevent accidents

Films and intensifying screens should be handled as little as possible This applies to the film in all stages of its progress through the dark room When it has been exposed it is best placed in a film hanger, in which it is then developed, fixed, washed and dried, so that it need not be touched from the moment it is taken out of the cassette to the time of its departure to the physician, surgeon, patient, or filing cabinet

The sure and safe handling of the film in the semi-darkness of the dark room is greatly facilitated by sufficient light. It may sound paradoxical to suggest light in a dark room, but this is a possibility provided the light is truly monochromatic There are certain wave lengths in the spectrum to which the silver bromide emulsion responds slowly, and a filter which allows these only to pass can be employed giving a very reasonable amount of light without danger, where a red glass allowing much less illumination might fog the films

It is a considerable convenience to employ both direct and indirect illumination, the former for momentary film examination, the latter for loading or unloading cassettes, which, notwithstanding the safety filter, should be done in as subdued a light as possible Two lamps can be used, one for direct and one for indirect light, or else one with a swivel holder will serve both purposes

Two other accessories in the dark room should be noted We have seen how extremely important is the question of temperature of solutions (page 117) A thermometer with which this temperature can be observed, and an electric heater with which it can be raised are essential Often it is found convenient to insert the four tanks in one large bath filled with water The temperature of this water can be raised by the heater in winter, or cooled with ice in summer, or in the tropics, and thereby the temperature of the solution is brought to the right level

TANK DEVELOPMENT BY TIME

The theoretical considerations of the developing process which are given above have taught us that, provided the exposure has been correctly made, there is for a particular temperature of solution a certain definite time for which the film must be immersed A shorter period will leave some of the energized silver bromide unreduced, and so omit available contrast, whereas a longer period will reduce silver bromide which was not acted on by X rays, and so produce fog

The treatment of films in dishes is unsatisfactory because one sensitive side of the film is bound to be in contact with the bottom of the dish, and unless the developer is agitated so vigorously that there is danger of splashing, the side in question will be faultily developed

The method of tank development, which was popular for plates years ago, has

therefore been resorted to again but with this difference Formerly very dilute solutions were employed for as long as half an hour or an hour whereas to day the solution is stronger and the film is immersed for five minutes or whatever period of time happens to be the standard for the particular developer at the particular temperature (see page 117)

The whole of the developing and fixing process takes place in four tanks made preferably of enamelled steel Three of these are narrow and high and have a capacity of 2 gallons They are filled respectively with (1) the developer (2) water for rinsing the film after development and (3) the fixing bath The fourth tank has a capacity of 8 gallons and is filled with water for washing the film after fixation A tap is provided so that water which must be at a temperature not exceeding 20° C (68° F) can be kept flowing through the tank

The object to be attained is to standardize the dark room process whereby the film which we assume to have been correctly exposed can be placed in the developer and fixer for certain times so that the radiologist can rest assured that the finished negative shows all that there was to show Not only does this standardization of dark room technique relieve the mind of the radiologist of worry when he does his own developing but it makes easy for him the task of teaching and supervising unskilled staff in these operations Provided such staff are cleanly in their dark room habits it becomes a matter of routine for them to produce negatives which are perfect from the photographic point of view

To sum up it will be found that the output of a radiographic department is improved by adopting the following standardized technique —

Developer Metol Hydroquinone made up as directed
Time of development Five minutes
Fixing solution Acid bath made up as directed
Time of fixation Fifteen minutes
Washing in slowly running water Thirty minutes
Temperature of all baths 18° C (65° F)

When the film has been washed it is hung up to dry in its hanger in some dust free reasonably warm and well ventilated place Care must be taken that the hangers do not touch the next film and that no draught exists which might be strong enough to make the films collide Hot air douches and similar methods of accelerated drying should be avoided

ERRORS IN EXPOSURE

Under exposure —When a film has been exposed for too short a time the amount of silver bromide which is energized and converted to metallic silver is too small There is a lack of contrast and a flat picture results

Attempts are sometimes made to correct such films by developing them for a longer time than the standard This is worse than useless because as we have seen (page 115) the standard time of development reduces all energized silver bromide and

comes to an end just when the rest of the silver salt commences to be reduced Prolonged development can only produce fog and a decrease in contrast.

Where the degree of under-exposure is slight, an improvement can sometimes be effected by intensification After the film has been fixed and carefully washed it is immersed in the following solution —

20 grammes Mercuric chloride.
1000 c c Water

Calomel (mercurous chloride) and silver chloride are deposited wherever there was metallic silver before After being rinsed in water the film is immersed in the following solution —

50 c c Concentrated ammonia
1000 c c Water

Here the two chlorides are converted to brown or black compounds of silver or mercury with ammonium and chloride The film, which assumed a grey or white tint in the first solution again becomes black We have therefore replaced the metallic silver by two insoluble chlorides which together are more dense than the silver was

In this way any contrasts which were present can be increased, but contrasts can only be intensified if they existed to some extent in the first instance Intensification is therefore a process of limited application only It yields its best results when a negative has been under-developed rather than under-exposed In such a case the contrasts are present but there is no density The adoption of standardized dark room technique, however, renders under-development impossible

Apart from this it must be noted that the mercuric chloride solution is a severe poison

Over-exposure.—The prospects of an over-exposed film are distinctly better There we are dealing with too great a deposition of metallic silver, but although a *reduction of the standard time of development might* correct matters a little, *it is* not to be recommended

The decision as to whether the negative is sufficiently dense would have to be taken in the dim light of the dark room and, very often, by others less skilled than the radiologist. It is better to develop fully and, subsequently, to dissolve some of the deposited silver out of the emulsion Reduction, as this process is called, is carried out in ordinary daylight, and can take place immediately after the film has been fixed and before it is washed A reducer can either be obtained ready and mixed and to be diluted 1 10 for use, or else it can be prepared as follows —

Solution A	1000 c c	Water
	100 grammes	Crystalline sodium hyposulphite
Solution B	100 c c	Water
(keep in dark bottle)	10 grammes	Potassium ferricyanide

Immediately before the reducing operation, 100 c c. of A are mixed with 10 c c of B The latter must be kept in a bottle of dark glass as it is sensitive to light.

Not only can a whole film which has been over exposed and is therefore too dense, be reduced, but parts of a negative which are too dense can be so treated. It will frequently happen, for instance, in lateral views of the head, that details in the cranium are clearly visible but that the exposure which was necessary to do this has made the part round the nose and sinuses too dense. Such over exposed areas can be treated with a wad of cotton wool steeped in the reducing solution.

When the reducing process has gone far enough, the film is carefully washed in water—as after fixing—and hung up to dry. The process can be applied again and again until the film has the correct density.

Apart from the fact that an attempt to correct for over exposure by under development leads to the dangers due to examination of the film in dark room light, it will be found that by developing fully for the standard time and then reducing if necessary, errors in exposure are more easily perceived and diagnosed. This permanent control of exposures is of considerable educational value.

SOME SYMPTOMS OF FAULTY TECHNIQUE

Grey Fog.—This gives rise to a lack of contrast in the negative and may be due to a variety of causes. There may have been over-exposure or, more likely, too hard a radiation was used. Furthermore, as we have seen, over development causes fog.

The most frequent source of the trouble is, however, the exposure of the films to X rays or ordinary light before use or before development. In the first case the film safe in which the unexposed films are stored is not ray proof, or else the film has been allowed to lie about in a cassette or envelope while X rays were turned on near by. The second case arises when the dark room lamp is giving out too much light or the wrong kind of light, or if the film is too frequently removed from the developing solution during the process. The tests to be applied are simple. In the first case, wrap a film in double envelopes and then wrap thick lead foil round half of the resulting package. After this has been left in the film safe for some days, remove the film and develop. If there is any blackening of the part which was not encased in lead foil, the film safe is not sufficiently ray proof. The second cause of fog, namely, faulty dark room lighting, is best tested by placing an unexposed film on the dark room bench and covering half of it with black paper. Turn on the dark room lamp for the time which is necessary to charge or discharge cassettes, then develop. Any blackening of the exposed part indicates faulty illumination.

A Yellow Fog is due to over-development or to the developer being exhausted.

A Dichroic Fog is the condition when the film appears yellow or orange in transmitted light, and has a yellowish or even metallic silvery lustre in reflected light. Such negatives sometimes look as if they had not been sufficiently fixed. The condition is due to the fixing bath being insufficiently acid or contaminated with developing solution.

White Half-moon-shaped Spots are due to careless handling of the film when it is placed into the cassette or during development. They are due in particular to

kinking and bending of the film, which give rise to more or less extensive and clear sickle shaped white spots

Handwriting and Dark or Light Markings and blemishes appear on the film when pressure has been applied to it in any way A ready cause for such pressure is when one uses the film in its wrapping or even the packet of films, as a writing pad

Round, Diffuse Dark Spots which are distributed over the whole surface of the film are caused when the film without being removed from the black binder in which even the ordinary wrapped films are placed is exposed to daylight. Black paper is always slightly porous and light can pass through the fine holes and act upon the photographic emulsion

Veins and Streaks *in the* **Gelatine** of the emulsion are due to impurities in the developer, particularly copper salts. These occur when hangers which are not made of the correct material are employed Hangers should contain as little copper as possible The same trouble arises very conspicuously when the film is frequently removed during development, for purposes of examination

Round White and sometimes Wholly Transparent Spots are due to bubbles of air which have become attached to the surface of the film and have prevented the action of developer on this particular spot.

The creation and attachment of air bubbles can be avoided by wetting the film before it is immersed in the developer, and by moving the developer about carefully *It is a good plan to move the film up and down once or twice in the hanger* before it is finally left in the solution

Finger Marks, Light or Dark Sharp edged Spots are due to the film surface having been touched with unclean fingers or else to the presence of splashes of other chemicals Splashes of developer solution produce very dark spots whilst those from the fixing solution give rise to practically transparent blemishes with a metallic lustre Even drops of water which are allowed to fall on the undeveloped film will appear on the finished picture as dark shadows because the spots which have been so wetted are more ready to be acted upon by the developer

Frilling Melting or Complete Detachment of the gelatine surface is produced *through too warm and uneven drying*

A further result of incorrect methods of drying in badly ventilated moist and warm rooms is the production of bacteria These cause a large number of holes of varying dimensions which appear quite transparent in transmitted light.

THE COPYING OF NEGATIVES

It may happen that a film is made of a subject of which a second picture cannot be obtained and where it is very important that a record is kept. In such cases the film should be copied on to another film before it is sent out. Thereby a positive is produced and by once more copying on to yet another film a second negative is obtained

Special process films with an emulsion on one side only are employed The process film is placed in close contact with the negative behind the sheet of

plate glass in an ordinary printing frame, and exposed to the light from an electric lamp The length of exposure depends on the density of the negative

The subsequent treatment of the diapositive film is exactly the same as for double coated films, and the same tanks and solutions can be employed

When the positive film has been washed and dried, the process must be repeated to obtain the fresh negative

It should be noted that the diapositive film is affected only by the contrasts on the original negative and not by any fog which may be present The new negative will therefore, show clear transparent parts It will present a very much better appearance to the eye than does a foggy original, although, of course, the degree of contrast in the original cannot be increased in the reproduced negative

REPRODUCTION OF PRINTS

A paper print from an X ray film, whether it be positive or negative, will never show us as much detail when it is examined, as it must be, in reflected light, as will the original film in transmitted light

Nevertheless, it is frequently necessary to make such prints for patients or records, etc

The bromide or chloride paper which is employed must have a glossy surface Matt surfaces show less detail than glossy ones

The process of copying is similar to that of making second negatives (see previous paragraph) Development takes place in a Metol Hydroquinone solution of exactly the same strength as for films It is, however, wise to keep the print developer in a separate bottle The reasons are first, that prints cannot be developed in tanks, but must be dealt with in dishes, and secondly, prints will show marks due to contamination of solution more easily than films, which are more robust in this respect

THE GOLDEN RULES OF X-RAY PHOTOGRAPHY

Strict cleanliness

When in doubt, over expose

CHAPTER VIII

CONTRAST AND DEFINITION IN THE X-RAY NEGATIVE

The excellence of an X-ray negative, from a diagnostic point of view, depends on the contrast and on the definition.

Contrast and definition are influenced by many factors, and in this book we can do no more than indicate in broad outline the more important of them. Those who would go more deeply into the subject are referred to an able monograph on the subject by Dr. Bronkhorst.

CONTRAST

An X-ray negative is a shadowgraph in which, however, there are not only black and white, or, rather, density and transparency. There is, in addition, every variation in density from complete transparency to complete opacity. The reason is that every object placed between the X-ray tube and the film allows the rays to pass to a greater or less degree, and upon this degree depends the density produced on the film

The art of radiography depends on the extent to which we can distinguish shadows of greater or less density from one another, and then upon the accuracy with which we can interpret the tale which these shadows tell

It is therefore of fundamental importance that adjacent shadows should differ *sufficiently in density to be readily distinguishable, and we call this difference in* density the contrast of the film

Apart from the atomic number and the density of the object, the factors which have the greatest bearing on contrast are—

1 The exposure
2. The wave-length of the X-rays
3. The intensifying screen.
4 Scattered radiation.

EFFECT OF EXPOSURE ON CONTRAST

Suppose that two objects, A and B, are placed on a film, and that A is twice as opaque to X rays as B B will let twice as much radiation through to the film as A The part of the negative under B will be more dense than that under A.

Obviously, if we do not expose at all there will be no densities produced and, on the other hand, if we expose sufficiently long we will energize all silver bromide particles under A, as well as all those under B In the latter case complete density all over will result.

There is, therefore, an optimum value between these two extremes where the difference in degree of density between the shadows is a maximum The exposure table on page 104 aims at giving this optimum value, but it must, of course, be amended for individual cases

In general it can safely be said that very many X ray negatives lack in density Viewing boxes are equipped with lamps of too low a candle power and with resistance dimmers in addition Better results could be achieved by making negatives which are of greater density and examining them in transmitted light of higher power In other words, the milliampere-second product should be increased—preferably by using larger currents

EFFECT OF WAVE LENGTH

Consider again our film and the two objects, A and B Very long wave rays (soft) will be almost completely absorbed by both No energy will penetrate and the film will remain transparent On the other hand, very short wave rays will penetrate both objects to an almost equal extent, producing nearly equal densities on the film Here again there is an optimum value of wave length or voltage between these two extremes at which the difference in quantity of energy transmitted by the two objects is greatest, and therefore also the contrast between the two resulting densities

Kilovoltages in diagnostic work have undoubtedly been too high There has been a good reason for this The intensity of the beam increases with the square of the voltage Generating units, and especially X ray tubes, have not hitherto been such that the heavy currents which are necessary for short exposures could be obtained The radiologist therefore helped himself by increasing the voltage and thus increasing considerably the intensity—but at the expense of contrast Nowadays transformer units which give from 100 to 500 M.A , and tubes which will stand these currents for periods up to 0 1 seconds, remove this trouble No part of the body should be radio graphed with rays at more than 85 K V , and Bronkhorst, in his experiments, has shown that by reducing the kilovoltage from 88 to 55, the improvement in contrast ranges from 30 per cent in the case of an aluminium object 12 mm thick (equivalent to say, 1 2 cm of human tissue) embedded in 4 cm of water (= blood, etc), to 125 per cent in the case of 2 mm of aluminium in 12 cm of water Recently some very striking lung pictures have been made at 26 K V and 1000 M.A

THE EFFECT OF INTENSIFYING SCREENS ON CONTRAST

In addition to decreasing the length of the exposure, intensifying screens always improve the contrast of a negative, and this effect increases as the amount of scattered radiation grows and as the penetrating power of the rays falls Screens are therefore

most efficient as contrast producers where thick parts of the body are radiographed with soft rays

This somewhat surprising phenomenon is explained by Bronkhorst as follows Consider a film without screens The primary rays upon which we rely for the image, strike the film more or less at right angles The scattered rays, on the other hand, strike it obliquely Since the photographic effect on the X-ray film takes place throughout the whole depth of the sensitive emulsion, it is evident that the scattered rays will convert more silver chloride particles, i e, produce more density, than will the primary rays

Now consider the same film but with intensifying screens The latter absorb both the primary and the scattered rays and convert them to fluorescence. The visible light thus generated is the active agent in making the negative, and not the X rays themselves Fluorescence is, however, a surface effect. Whether the rays strike the screen surface at right angles or obliquely does not influence matters The relative importance of the scattered rays as compared with primary rays is therefore diminished

From this it follows that negatives which have to be made when the amount of scattered rays is large will benefit most from the use of screens Moreover, such negatives will be *still further improved when the kilovoltage which generates the rays* happens to be low, because then the penetrating power of the scattered rays is also low and they will be almost entirely absorbed by the screen

The improvement in contrast in a negative of an object surrounded by 8 cm of water when radiographed at 88 K V without screens, and at 55 K.V. with screens, is from 100 per cent to 150 per cent. A further result of this is that when hard rays are used with *screens*, the *same* contrast will be *produced as* when *soft* rays are used without screens

Modern screens are so free from grain that they produce no blurring of the picture on that score The considerations mentioned above indicate that screens should be used in all radiographic work, and especially when lack of current compels the use of high kilovoltages or when scattered rays are unavoidably present.

EFFECT OF SCATTERED RADIATION ON CONTRAST

Reference to Fig 72 and to the remarks on page 66 must convince us at once that scattered rays will tend to reduce contrast in an X ray negative This, of course, is well known to every radiologist who has once used a Potter Bucky diaphragm and thereby greatly eliminated scattering

A less obvious but very important consideration is that even comparatively thin parts of the body scatter to such an extent that the use of a Potter Bucky diaphragm appreciably increases contrast. Thus the contrast in a negative made at 55 K.V of an object embedded in 8 cm of water is improved from 65 per cent to 83 per cent, according to the thickness of the object, when scattered rays are eliminated At 88 K.V the improvement is from 100 per cent to 165 per cent.

When the surrounding water is 12 cm deep the figures for 55 K V are 85 per cent to 165 per cent, and for 88 K V 110 per cent to 190 per cent

It follows from this that the use of the Potter Bucky diaphragm is imperative in all radiography of thick parts and that it is very advisable even for arms and legs

From what has been said on page 127 it is evident that the intensifying screen loses its contrast producing properties when scattered rays are cut out On the other hand the Potter Bucky diaphragm reduces the intensity of the primary radiation to about one half and therefore renders more current or longer exposure necessary The intensifying screen counteracts this

DEFINITION

By definition in an X ray negative we mean the sharpness of the edges of the various shadows A shadow may be such that its density will not vary as we pass across it till we reach the edge where there will be a sudden jump to the lesser density of the surrounding area On the other hand we may come to a region at the edge of the shadow where the density gradually lessens till it reaches that of the surrounding area In the first case the definition is good and in the second case bad

The factors which influence definition are the relative distances of focus and object from the film and the size of the focus In Fig 111 we see a diagrammatic representation of a general case in which F is the focus O the object and S the film or screen One end of the focus casts the shadow ac and from the other end we get bd It will be seen that these overlap and so we have a shadow bc of complete density surrounded by a region ab and cd on each side in which the density gradually falls off—a region of half shadow or as the astronomer calls it, penumbra

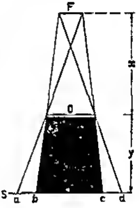


Fig 111

In order that we may get good definition this half shadow region must be reduced to a minimum and there are various ways of doing this

Suppose that focus-object distance is x and the object film distance is y then considering similar triangles we have —

$$\frac{ab}{F} = \frac{y}{x}$$

$$\text{or } ab = F\frac{y}{x}$$

From this we see that we can make the half shadow region ab very small by reducing the size F of the focus or the distance y from object to film or else by increasing the distance x from focus to film

The limit which we approach in reducing the size of the focus is a point and Fig 112 shows us how in such a case the half shadow region vanishes Unfortunately

a point focus is impossible for reasons which have been discussed in the chapter on tubes (see pages 4–16). All that we can do is to make the focus as small as possible by adopting the principle of the line focus (see page 14).

Fig 112.

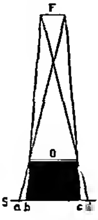


Fig 113

The next step towards good definition is to see that the object shall be as near the film as possible. *Fig 113 shows us* how the half shadow region ab becomes smaller when the object is moved nearer the film than in Fig 111, other things remaining equal. Here again there is an obvious limit, since several of the objects which are regularly radiographed cannot be brought in close contact with the film.

There remains the third factor, namely the focus-object distance which can be increased, and this has given rise to the practice of teleradiography.

TELERADIOGRAPHY

By this we mean the placing of an X ray tube at a considerable distance (say six feet) from the object and film, which themselves are close together.

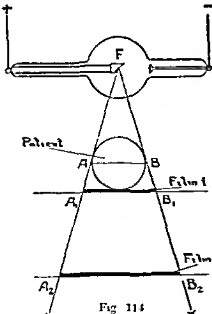


Fig 114

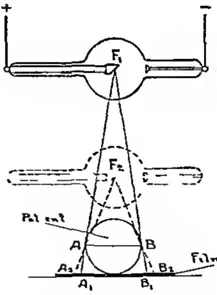


Fig 115

The first goal to be achieved is that the size of the shadow shall be approximately equal to the size of the object. Fig 114 *shows how the shadow of an object*

AB increases from A_1B_1 to A_2B_2 if the film is moved too far away On the other hand, Fig 115 shows how the size of the shadow A_2B_2 of an object AB decreases to A_1B_1 when the tube focus is moved from F_2 to F_1 whilst the object AB and the film remain stationary We see that A_1B_1 is more nearly equal to AB in size than is A_2B_2

The next achievement of teleradiography is greater definition Fig 116 shows us how half the shadow area ab is reduced as compared with Fig 111, when we move the focus to a distance and leave the size of focus and the object film distance the same

There are, however, two more reasons why teleradiography should be employed in certain cases The first of these is merely a special case of the more general one discussed above It occurs wherever it is necessary to make even the smallest objects

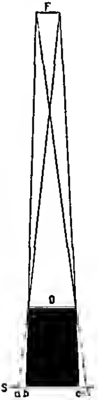


Fig 116

Fig 117

Fig 118

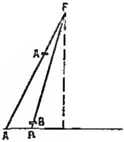


Fig 119

Fig 120

throw as distinguishable a shadow as possible, as, for instance, in the early diagnosis of tubercular conditions In Fig 117 we see a very small object and a relatively large focus We observe that the cone of complete shadow, which is shown entirely black, comes to an end before the film is reached On the film itself we get a pseudo shadow cb of less density because no part of the film is in the cone of complete shadow Astronomers would immediately recognize in this the phenomenon known as annular eclipse of the sun

Now let us move the focus far away leaving the object at the same distance from the film as before (Fig 118) The film is then in the cone of complete shadow Not only is the half shadow region round the edges made smaller but the pseudo shadow becomes a true shadow and has therefore its maximum possible density

The third important reason for teleradiography becomes apparent from Figs 119 and 120 The relative positions of two shadows A_1 and B_1 of two objects A and B which are at different distances from the film may be entirely different according to whether the tube is near to or far from the film In Fig 119 we see the shadow A_1 to the left of B_1 and in Fig 120 it is to the right In other words the nearer the tube focus is to the film the greater is the danger of distortion and apparent displacement By making the distance of the focus to the film large we decrease the divergence of the beam of X rays we make the rays more nearly parallel and we obtain a truer representation on the film of the relative positions of the objects

The trouble hitherto has been that the intensities of X rays which were available were too small to take radiographs at these distances in the short times which are necessary Now that tubes exist which can take large currents there is no doubt that teleradiography will become much more general

CHAPTER IX

THE PRACTICAL APPLICATION OF X RAYS IN THERAPY

THE advantages which diagnosis derived from the discovery of X rays surpassed the most sanguine expectations, but the benefits conferred on mankind by their therapeutic applications have nowadays become equally great and are still growing from year to year

In the following pages are given some hints regarding the practice of radio therapy, so far as the physical and technical sides of the subject are concerned The purely medical aspect is beyond the writer of this book, and therefore it creeps in only occasionally in the form of a reference to a standard author or a quotation from his work The reader is referred to such publications for details

X rays are now the therapy of choice in many diseases of the skin They are of importance in ear, nose, and throat cases, in exophthalmic goitre, in some dental cases, and even in the treatment of tumours of the brain We find them applied in affections of the blood, such as leukæmia, of the nervous system, such as neuritis and neuralgia, in cases of arthritic joints, and, lately, in the treatment of malaria and typhoid

The most striking field of X ray therapy is undoubtedly still gynæcology In the treatment of excessive hæmorrhage, due to the approaching climacterium or to fibroids or myomata 100 per cent of cures *without a single failure or mishap*, are claimed and admitted and this is achieved by exposures to X rays lasting no more than 1½ to 2 hours altogether, which scarcely interferes with the daily occupations of the patients

The value of X ray therapy has often been estimated by its success or failure in cases of carcinoma There has been a tendency to overlook the large field of therapy which is briefly outlined above, and in which quiet successful work has gone on for years As a result, X rays have been condemned as a therapeutic medium because of their apparent failure in the treatment of cancer This is erroneous for two reasons First malignant disease is only one—though admittedly a very important one—of the spheres of usefulness of X rays there are many others which are still but imperfectly explored Secondly, although the wild claims which were made some years ago have not been realized it is a fact that in most sarcoma and in many carcinoma cases the results obtained are already as good as many which are achieved in surgery, and this at a time when X ray therapy is still in its infancy Well known

authorities claim from 28 to 69 per cent three year cures in operable cases, and from 14 to 17 per cent five year cures in inoperable ones

Such results give X ray therapy a position of unquestioned importance, both on account of what can already be achieved and because of the promise of still better things when knowledge grows and technique improves

The technique of the *diagnostic* applications of X rays can be learned in a few weeks Mistakes can be overcome by repeating the exposures without risk of doing harm In radiotherapy, however, this is different The doses required to produce the biological changes are fifty to several hundred times as large as those required for diagnostic purposes The effects which X rays produce cannot be seen for several days and harm is sure to be done when the correct dose is considerably exceeded, and, in a few cases, even when it has been too small The difficulty, the art, and the skill of the treatment consist in applying to the organ we wish to treat a dose sufficiently great to produce the desired effect without injuring other organs

To be successful with therapeutic exposures, especially those for deep-seated malignant diseases, considerable knowledge, skill, and experience are required to master the correct quality, dose, and direction of the X rays On the other hand, medical men can certainly learn it in as many months as it will take years to learn to perform efficiently some of the surgical operations which can now be replaced with equally good, or even better, prospect of success by exposure to X rays

Therapeutic exposures should be made under the supervision of medical men only, and those for the treatment of deep-seated malignant diseases only by those who can devote their whole time and attention to this subject

X rays act like a poison on animal tissues If doses of sufficient strength are applied, cells become irritated, blisters, inflammations and changes in the blood are produced and the cells may even be killed Small animals exposed to a certain dose invariably succumb

That we may employ X rays as a curative agent is due to the fact that the *susceptibility of different groups of cells varies* a good deal Young and rapidly growing cells are much more susceptible to this poison than older cells in which metabolism has become less active Hyperæmic tissues are more susceptible than anæmic ones, whilst spermatozoa and ova may be killed, and embryos or the growing seeds of plants may be retarded in growth or permanently injured by doses of X rays which are not yet sufficient to leave any visible effects on older cells Moreover, the cells of malignant disease may be killed or at least paralysed by doses which produce only a temporary slight inflammation of the skin

The Biological Influences of X rays—Whether the X rays have a *chemical* or electrical, or mechanical influence on animal tissues, is not yet fully understood Several theories have been put forward (see page 68) X rays are not felt, and weak doses produce no visible effects, but it is known that in cells which have absorbed a dose of X rays of sufficient intensity, the *faculty of the chromosomes* and cells to divide and multiply is impaired They may recover, but when the dose has reached a certain strength the cellular nuclei disappear, and necrosis of the cells follows

The changes produced vary in wide limits with the susceptibility of various groups of cells, and with the quantity of X rays which have been absorbed They do not become noticeable to our senses immediately after the exposure, but with the microscope or chemical analysis some effects of even weak doses can frequently be observed within half an hour after an exposure When the skin has been exposed to moderate doses which will cause an erythema to appear about a week afterwards, a faint redness and a slight itching or burning sensation are noticed by many patients within thirty minutes after the exposure The intensity of the injury which will follow is determined already at the time the exposure is finished

Susceptibility of Different Organs—The groups of cells most sensitive to X rays are the lymphatic tissues and glands, the leucocytes, ovaries, testicles, the suprarenal, and various other glands with internal secretion, like the thyraid, the thymus, hypophysis, the spleen, etc Considerably less sensitive are the skin, the mucous membranes, the follicles of the hairs, the liver, the kidneys, etc The cells of the muscles and bones are the least sensitive Doses which are over 100 times as great as those which are lethal to ova or spermatozoa, will only begin to produce noticeable effects on bones Even in the same group of cells the sensitiveness varies, the same dose may prove lethal to many of the cells, whereas others are only paralysed for some time, and recover It is supposed that those cells are most vulnerable to X rays which are near the stage of division, whereas those at rest are less susceptible

Increased Activity or Stimulation, Paralysis, and Necrosis—According to the strength of the dose absorbed by the tissues, and their vulnerability, an increased activity, a temporary or permanent paralysis, atrophy, or necrosis, will follow the exposure

The increased activity due to the irritation caused by weak doses is frequently called "stimulation" It is only temporary, and lasts till the irritation has subsided, and its causes have been repaired It may be repeated once or twice, but it has to be remembered that for a considerable time after the effects which are noticeable to our senses, or which can be discovered even with the microscope, etc, have passed away, a second exposure has a "cumulative" effect Whether this time of increased susceptibility lasts only a few days, or some weeks, or even several months, depends on the quantity of X rays which have been absorbed, and on the organs which have been exposed "Stimulating doses" cannot therefore be repeated as frequently as we would like to do it, because even weak doses repeated too frequently will produce toxic effects The best proofs for this are the hands of numerous medical men and engineers, who exposed them too frequently in the early years, before these toxic effects of the X rays were sufficiently known

The boundary line between the weak dose which merely irritates so far that it can be called stimulation, and that which begins to paralyse, seems to be very narrow It varies with the susceptibility of various organs It is also impossible to limit the action of the rays to a certain group of cells only, without affecting others, for instance, the lymphatic tissues and the blood, at the same time Also it seems difficult to decide whether some of the effects are due to "stimulation" or to incipient paralysis of the functions of some cells For instance, when the spleen or the lymphatic

tissues have been exposed to a moderate dose, more leucocytes and lymphocytes are found in the blood soon after the exposure The former may have increased to four times the number which were present before the exposure, but some hours afterwards their number begins to drop below the normal The time which elapses before this drop begins and the intensity of it, vary with the doses absorbed, and with the organs which were exposed The increase at the beginning seems to be due only to a more rapid expulsion of the leucocytes etc, from the cells which produced them They empty their stores at a quicker rate Provided the X ray dose was not too strong, a recovery sets in gradually, and the cells resume their normal function and rate of activity after some time The blood may show its normal composition again in anything between from 3 to 90 days, according to the quantity of X rays which has been absorbed by it When the region of the kidneys has been exposed the quantity of urine secreted increases, and so does the normal quantity of uric acid, sodium chloride, calcium, and other minerals contained in it

The paralytic effects can be more clearly defined than the much-disputed "stimulation" The dryness of the mouth and throat, for instance, of which some patients may complain even after a very prolonged examination on the fluorescent screen, is due to a paralysis of the salivary glands The function of the ovaries can be paralysed by moderate doses to relieve excessive hæmorrhage

Diseased or inflamed cells are slightly more susceptible to X rays than healthy ones, and are therefore eliminated at a quicker rate after exposures to moderate doses It is likely that this is the reason why swellings or tumours begin to shrink The healthy cells in the neighbourhood then find more room for expansion The greater activity which can be noticed in the adjoining healthy tissues may be due partly to this and partly also the increased irritation due to the greater quantity of necrotic matter which has to be eliminated The X ray sickness which begins to appear after exposure to moderate or strong doses is most likely largely due to this cause too

With doses of sufficient strength the irritation becomes so violent that even organs like the skin etc become atrophied and shrink, or when the exposure was excessive, ulcers and abscesses begin to form

Any of the various degrees of irritation caused by X rays, the temporary stimulation, temporary or permanent paralysis atrophy, or even necrosis of some organs may be used therapeutically in suitable cases

Some General Considerations —It is important to remember from the start that the biological effect on any particular cell is proportional to the quantity of X rays which has been absorbed Moreover, we cannot cause X rays to be absorbed by some particular part of the body, either on the surface or deeper down without at the same time irradiating those tissues which lie below or above the particular part Evidently the danger to those below is not so great as to those which intervene between the tube and the organ to be treated This is because increasing distance and absorption by supervening tissue weakens the X ray beam, and so the parts below the spot where we want to concentrate a definite dose will receive less than that dose, but those above will receive more, unless we take careful steps to avoid this

There are two important points in radiotherapy which have been the subject of much discussion In the first place, what is the correct dose? Different organs and different conditions will obviously call for different doses, but what, in each particular case, is the right one?

For a long time it was definitely asserted as stated above, that a weak dose stimulates the individual cells to increased growth, that a medium one paralyses, and that a strong one will kill cells The school of radiologists at Erlangen were emphatic that only large doses could achieve the desired results, and that small ones aggravated various conditions This is much disputed now, particularly by Holzknecht, who is of the opinion that every dose of rays, no matter how small, acts detrimentally on the individual cell, but that if the dose is not large enough the cell will recover If a small dose is applied to a growth certain cells only will die, and the others can, when the irradiation has ceased recover and expand at the expense of the dead ones, thus giving an impression of increased activity

Arising out of this is the second much-debated point—namely, should the dose which is required for a particular condition be given all at once, in as short a time as possible, or should it be spread in small fractional doses over a long period? In speaking of the photographic effect of intensifying screens as compared with that of X rays by themselves, we noted (see page 105) that the result produced by the rays of visible light is not proportional to the product of Intensity by Time, but to the product of Intensity by a fractional power of Time, i e,

$$D = I\ t^p$$

where p has some value less than unity In other words if we produce a certain effect with a certain intensity in a certain time, we will produce a greater effect by doubling the intensity and halving the time It seems not unlikely that the same sort of thing may apply to the biological effect of X rays, that if the dose given in one sitting is large enough to produce the desired effect, a considerably larger total quantity would have to be given if fractional doses were administered with several days' or even weeks' interval between each

Even the same physical dose, when given in 10 minutes, seems to have a greater effect than when it is applied in 40 minutes If the same current, kilovoltage, and X ray tube are used in one instance with a focus skin distance of 25 cm, for an exposure of 10 minutes duration and in another instance with 50 cm focus skin distance for an exposure of 40 minutes' duration, the *physical* dose received by the skin is the same, owing to the inverse square law, and an Iontoquantimeter indicates the same result in either case, but experiments on plants and animals, and clinical experience, prove that the same physical dose given in 10 minutes produces a more intense biological effect than when it is spread over 40 minutes The biological difference in favour of the shorter exposure with more intense rays is as great as 20 per cent and where X rays are to be used as a destructive agent it is a great advantage that it has become possible to reduce the duration of the exposure very much The cells have a tendency to recover until they have been subjected to a lethal dose and though they may not recover to their initial condition between one sitting and

the next, the total aggregate dose must be larger because each bit of recovery must again be defeated

The application of the whole dose in one sitting is therefore recommended by the Erlangen school, and many others have adopted it. The chief objection against it is that some feeble and nervous patients cannot stand the strain and discomfort, especially when the carcinoma dose has to be applied and that X ray sickness (see page 158) appeared in a few instances in such a violent form that the patients succumbed to it

Experience on the other hand, has also shown that in gynæcological conditions it is possible to produce sterilization with a large number of very weak doses In a report made before a medical society in Paris, Dr Beclère stated that he had treated successfully some 300 cases of profuse hæmorrhage with exposures of only five minutes' duration each but continued over several months until the hæmorrhage ceased In the majority of these cases sterilization occurred after total exposures of between two and three hours had been given This means an average of 25 separate exposures of five minutes each for each case

The advantage of these very small doses is that no trace of X ray sickness was ever noticed, but it is surely a great loss of time and money, which many patients cannot afford, and which would be dangerous with malignant diseases Nogier has also shown that frequently repeated exposures to weak doses produce a certain immunity of the carcinoma cells against X rays, and that they act too slowly and allow a dangerous condition to exist too long

The position at present seems to be that the extreme Erlangen technique of huge doses at one sitting has been entirely given up except in some isolated cases of carcinoma It is quite likely that in most other fields of X ray therapy the reduction in total dose and particularly the subdivision into small fractional doses has not yet reached a limit.

Which is the Best Quality of X Rays for Therapy?—The quality—i e., the penetrating power or wave length—of the rays must vary according to whether the part to be treated is on the surface, or just below it, or deep down The rays can be softest when they are to be absorbed near the surface, and must be hardest when they are wanted at a depth Investigations have been made to find out whether there is any variation of biological effect with wave length Up to the present it seems that within the range of wave lengths from soft X rays to hard γ rays from radium no such variation exists The biological effect appears to be solely proportional to the quantity of energy of radiation which has been absorbed

For a time it was argued that the highest available voltages were the best, and attempts were made to employ 250 K.V and more The chief argument in favour of this step was that the intensity increases as the square of the voltage, but this is more than counterbalanced by the fact that the absorption decreases with the cube of the voltage

The best wave length to use is the one which causes a sufficient dose to be absorbed at the spot where it is wanted without injuring the skin or overlying tissue

If the penetrating power is increased beyond this, the exposure has to be prolonged needlessly, without any corresponding gain in therapeutic effect

A voltage of 200 K V is probably the upper limit to which it is advisable to go More than this is not only unnecessary, but not so advantageous

It may of course be that if tubes and transformers are produced for 1000 K V, we might find the quality of biological effect changing because some other part of the atom (see page 58), possibly the nucleus, would be excited, but this development is still some way off

As things are the voltages and filters mentioned by Holzknecht may well be accepted as standards

Case.	Voltage	Filter
Skin	100 K V	0 5–1 0 mm aluminium
Medium deep therapy	120 K V	1 0–4 0 mm
Deep therapy (lymphatics myomata leukæmia etc)	160 K V –180 K V	0 2 mm copper plus 1 0 mm aluminium
Deep therapy (carcinoma)	170 K V	0 5 mm copper plus 1 0 mm aluminium

The intensity of the radiation can now be increased by raising the milliampèrage, since tubes and transformers exist which can stand up to these higher outputs for long periods and this is a more promising method to adopt than the raising of kilovoltage beyond what is necessary

The Dosage for Therapeutic Exposures —The accepted unit for biological effect in therapy at the present time is that dose which will produce erythema (see page 86) Perhaps we will in time have a more definite unit, such as the lethal dose for particular kinds of cells, and this would be more acceptable because it would probably be more definite and less subject to the age and idiosyncrasy of the patient As it is, the erythema dose varies by as much as 10 per cent between one patient and another A most useful step would be to establish, if possible that various kinds of carcinoma react to various doses of radiation, each of which would be quite definite for the particular form of the disease

Ever since radiotherapy has been carried out attempts were made to link the unit of one of the chromoradiometers (see page 82) to the erythema This, however, proved difficult because the quantities of radiation absorbed by the barium or silver salts of radiometers on the one hand, and the skin on the other, varied with the wave length Moreover, the variations were not the same The absorption by the skin decreases more rapidly as the rays grow harder than does that of the radiometer salts The result is that if a certain radiometer effect (e g, the B tint) indicates an erythema for soft radiation, it will indicate considerably less for hard rays

This trouble is about to be solved by the introduction of the ionization unit "one Rontgen" (1 R) This keeps step with the skin when the wave length is changed provided that the ionization chamber is correctly made Moreover, the newer instruments are calibrated in R units and erythema is produced by approximately 550 R

The iontoquantimeters reading R units are not yet very frequent, and so it is best to dose by the method described on page 87, where the kilovoltage,

milliamperage, and time are measured and compared with the effect produced by a standard tube

Empirical Determination of the Erythema Dose —The dose which produces erythema is the unit for all therapeutic exposures It is frequently referred to as the ' Unit Skin Dose" (U.S.D) and figures in most Continental literature as H E.D "—from the German, Haut Einheits-Dosis

The radiologist who wishes to carry out therapy is well advised to find out empirically in what time he can produce the U.S D under certain conditions of current, kilovoltage, distance filter etc., and with a certain tube This tube he then regards as his standard tube by which he can easily calibrate all his other tubes—using the method described on page 87 In doing this, he will not only gain practice and *experience in handling his apparatus*, but he *will establish once and for all his own* dosage meter in terms of the U.S D , or, if he has an iontoquantimeter calibrated in R units he will have a valuable means of checking the readings of that instrument

The duration of the exposure which is necessary to produce a U.S D depends on many factors The most important are the voltage, milliamperage, focus skin distance, and filter It is influenced also by the type of apparatus which is used For this reason it is not possible to give more than very approximate figures when an installation is first set up and the actual time for the U.S.D must be found experimentally

Thus, for instance, an unfiltered radiation at 70 K.V with a current of 2 5 M.A and a focus skin distance of 25 cm will set up erythema in 6 to 8 minutes Under similar conditions but with a voltage of 120 K.V , the exposure will have to last about 12 minutes because harder rays are absorbed in smaller quantity When a filter of 3 mm of aluminium is used 15 to 25 minutes are necessary At 150 K.V and with a copper filter 0 5 mm thick the U.S D can be produced in from 10 to 30 minutes according to the current which is used

To find the exact time for the U.S D we can bear in mind that with a copper filter 0 5 mm thick and a voltage of 120 K.V , we must give about 3 5 B (Sabouraud) doses before the U.S.D is produced—it being understood that the pastille is exposed at half the distance from focus to skin, and on the skin side of the filter

If the focus *filter* distance is 15 cm and a Sabouraud pastille exposed just *below the filter (it should be attached to the central part of the filter with wax) shows* Tint B after an exposure lasting 15 minutes, this would mean that with a focus skin distance of 30 cm the full erythema dose would at any rate require more than three times 15 i e , 45 minutes and it would be safe to give an exposure of this duration without fear of exceeding the erythema dose If 45 minutes can be given with a focus skin distance of 30 cm., we can calculate the time for which it is safe to expose at, say, 23 cm by applying the inverse square law It is $45 \times \frac{23^2}{30^2} = 26.5$ minutes, or, at 20 cm it would be $45 \times \frac{20^2}{30^2} = 20$ minutes

If, on the other hand, an ionization instrument calibrated in R units is available, we can remember *that 550 r roughly equal one U.S.D* and we can *ascertain*

the approximate time by placing the ionization chamber at the full focus skin distance and exposing till 550 R have been recorded

When the approximate time has been determined experimentally in one of these ways, exposures should be made on an arm or a leg and should be gradually increased till the time in which the erythema is produced has been found

As this may be a somewhat tedious process, it is well to bear in mind that patients whose ovaries have to be sterilized on account of profuse hæmorrhage are convenient subjects for calibrating tubes because there is no risk whatever to the patient herself The ovaries are so much more sensitive to X rays than the skin that about 0 3 U S D suffices to produce sterilization

Suppose it has been found that at 150 K V with a copper filter 0 5 mm thick, a diaphragm with 6 × 8 cm opening and a focus skin distance of 23 cm the standard tube gives the U S D in about 24 minutes Suppose also that we have found by the method described on page 89 that the depth dose at 8 cm is 25 per cent An ovary situated at this depth will receive 0 5 U S D in 48 minutes This evidently will give to the skin above, a dose which is decidedly more than one U S D and would therefore injure it The 48 minutes must, therefore, be spread over two windows by the cross fire method (see page 151) and each receives 24 minutes

If it should turn out afterwards that the 24 minutes did not produce erythema and that as much as, say, 35 minutes would have been required with the tube and under the prevailing conditions of filter, diaphragm, distance, etc, the two windows together would have received with the 48 minutes' exposure a total of $\frac{48 \times 100}{35} = 137$ per cent, and the ovaries $\frac{25 \times 137}{100} = 34$ per cent of the U S D This is still sufficient to produce the desired sterilization

The appearance of the skin in this first patient will most likely give some indication whether an erythema would have resulted if the exposure had been continued for, say, five minutes longer To find this out, other trial exposures can be made The next patient can be given 25 minutes through one window and 23 minutes through the other, and so on

Eventually the exact length of exposure for the U S D under given conditions with a standard tube and within the 10 per cent variation which occurs between one patient and another, will have been found Any other tube can then be calibrated against the standard one, and, moreover, the size of diaphragm, nature of filter, distances, current, and voltage, can be altered and the new value of the exposure for U.S D can be found by simple comparison of the times of discharge of the ionto quantimeter

This determination of the U S D requires a little patience on the part of the radiologist, but repays him by giving him a better control over his apparatus and measuring instrument than he can get by other means

Filters —The action of the filter has been described on page 67 Certain filters have become standard nowadays, namely 0 5 mm 1 0 mm 2 0 mm, and 3 0 mm of aluminium, and 0 2 mm, 0 5 mm, and 1 0 mm of copper

These are inserted in a slot in front of the tube box in case of Coolidge tubes When Metalix tubes are used the filter is screwed into the tube itself

It is, of course, all-important that the filter shall not be forgotten. Omissions of this kind have been known to produce fatal results owing to overdosage.

Those who fear that assistant staff might forget to insert the filters can make use of a simple contrivance As shown in Fig 121, it is arranged for gas tubes, but it can, of course, be applied to Coolidge tubes equally well, and with suitable modifications to Metalix tubes All tubes are provided with rings at both ends, and the high tension leads from spring reels have hooks to be attached to these rings If one

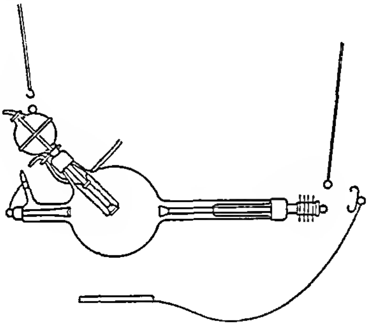


Fig 121

of the cords is provided with a ring too, and *all* the filters with a short silk cord carrying a double hook at its end, as shown in the illustration (Fig 121), the connection cannot be made without this double hook, and the operator is thus reminded of the filter if it should have been forgotten Different metals can be provided with silk cords of different colours—aluminium white, copper red, etc

SOME HINTS FOR SKIN THERAPY.

Soft rays are no longer used even for the treatment of skin diseases The voltage that is applied to the tube is not less than 100 K.V. and filters of aluminium 1 0 mm to 3 0 mm thick are employed.

The difference which these filters make can best be shown by the experience gained in epilation. When *no* filter is used the *full* erythema dose has usually to be

applied to cause all the hairs to fall out, when a 3 mm aluminium filter is used 0 6 i e, little more than one-half, of the erythema dose is already sufficient to produce complete epilation and *no inflammation* or reaction whatever will appear on the skin The duration of the exposure will be three times as great as it would be without a filter being used but in most cases this will be amply compensated by the absence of any inflammation It is obviously better that the filter should absorb the softest rays, which cannot even penetrate to the roots of the hairs than that they should be allowed to produce a useless inflammation

On the other hand, filters which are thicker than 3 mm aluminium should not be used for skin diseases, except in cases of malignant diseases extending lower down, as otherwise rays of too great a penetrating power would reach the patient and healthy organs lying deeper down would be exposed to unnecessarily large doses

Dosage in Skin Therapy—Sabouraud and Holzknecht radiometers have been used for years and are still popular in skin therapy The Holzknecht instrument indicates fractional doses of the U.S.D The Sabouraud radiometer only shows the B tint which is 0 8 U S D, but it can be made to show smaller fractions or multiples of the U.S D by altering the focus pastille distance If the distance between the skin and the anticathode is 20 cm, the epilation dose will be obtained when a Sabouraud pastille exposed at 10 cm from the anticathode assumes Tint B But if a pastille is exposed at this distance, and the distance between it and the skin is *increased* to 15 cm, the skin will have received only two-thirds of the epilation dose when the pastille assumes Tint B By varying the distances suitably, fractions of the epilation dose can be measured On the other hand by making the distance between the pastille and the skin *less* than the distance between anticathode and pastille, multiples of the epilation dose can be measured Actual figures for these distances are given on page 88 in the chapter on Dosage

The most satisfactory method of dosage in skin therapy, as in all other radio therapy, is with a standard tube or with a reliable instrument calibrated in R units as outlined on page 87

Even Distribution of Intensity over the Diseased Area is of great import ance If, for instance, in epilation for ringworm a small patch does not absorb a dose which is sufficient to cause the hairs to fall out the disease is most likely to *spread again from this patch*

Analogous conditions exist with many other diseases It is rather difficult, or impossible, to correct such errors with subsequent exposures because the sensitive ness of the skin has become changed by the first exposure and remains in a very uneven condition for several months

Unless the diameter of the diseased area is quite small it can be exposed to a dose of uniform intensity only if it is spread over a circular concave area with the anticathode in the centre of it, but such conditions are very rare with skin diseases If the diseased area is spread on a fairly level surface and the central ray falls perpen dicularly on it, the middle of the area receives a greater intensity than those parts which are some distance away from this spot partly because the distance which the rays have to traverse becomes greater, and partly because rays striking an object

obliquely have a smaller intensity than those striking it perpendicularly The smaller the focus skin distance, the greater will be these differences as is evident from the illustration (Fig 122) The distance a b is shorter than a d by b d, but when the focus skin distance is increased the difference between the two is h d and is smaller

In Fig 123 the difference of distance of the two rays due to increasing obliquity becomes still more apparent

Fairly even irradiation could be achieved by choosing large distances, but the duration of the exposures is thereby increased so considerably that the inconvenience and expense become too great, and with convex surfaces like the head not even the longest distances would give satisfactory results with one single exposure *To obtain a sufficiently uniform irradiation of flat surfaces of larger area, or of convex surfaces,* it has been found that the distance between anti cathode and skin should be *at least twice as long as the diameter of the irradiated area* If the diameter of the diseased area exceeds 15 cm, it is better to divide it into several smaller fields, to be exposed separately, than to have to increase the focus skin distance beyond 30 cm The total time required for *one* exposure with more than 30 cm distance will

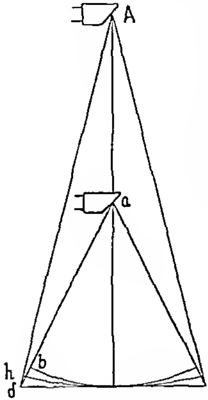


Fig 122.

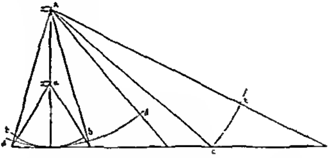


Fig 123

be considerably greater than the sum of several exposures with only 20 cm distance each

It is not advisable to use several different focus skin distances because this would necessitate a fresh calculation of the exposure for each distance used. It is more convenient to concentrate on two distances 20 cm for areas not exceeding 10 cm in diameter 30 cm distance for areas between 10 and 15 cm diameter The intensities obtained nowadays with good modern apparatus are so great that the exposures can be finished in a reasonable time even at the 30 cm focus skin distance We thus have the advantage of obtaining greater uniformity in the intensity over the whole area and the convenience of using not more than two different durations of exposure to produce the erythema dose in all skin work

If the diameter of the area exceeds 15 cm it is divided into several fields, each of which receives a separate exposure. It is best to map these out carefully and to mark the outlines with coloured pencil on the skin, or to make a plan on paper to find the points which should be struck perpendicularly by the central rays. These spots are marked. It is a help if a wooden rod of suitable length can be attached to the tube box so that it is centred and projects in the direction of the central ray. The tube is then shifted till this rod touches the spot through which the central ray should pass perpendicularly. The rod is removed before the exposure begins.

Other contrivances exist serving the same purpose, for instance a telescopic centimetre rule, or a tripod with three rods converging in the centre may be attached to the tube box; if the rods are made of thin transparent wood such a tripod may even be left in position during the exposure, as the rods absorb very little of the rays.

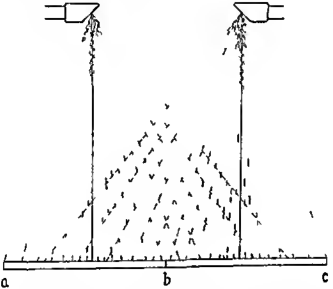
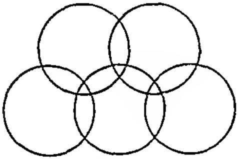


Fig 124

Formerly, it was attempted to expose rectangular areas about 8 × 8 cm wide and the adjoining ones were protected with lead rubber. It is not possible to obtain satisfactory results in this way because the frontier lines will either receive double exposures or no exposure at all. It is a much better plan to let the exposures overlap the adjoining areas. The intensity of the rays diminishes gradually the farther away they are from the central rays, but the difference is made up because these parts receive a second or third exposure by the rays overlapping when the adjoining area is exposed (see Figs 124–126). A circle of 25 cm diameter may be divided into 5 areas as indicated in the illustrations. Even the surface of convex objects like the head can be subjected to sufficiently homogeneous intensities in this way. It can be mapped out in 5 circles of about 10 cm diameter each and exposed with focus skin distances of 20 cm. If the circles overlap sufficiently, complete epilation can be achieved without causing any inflammation.

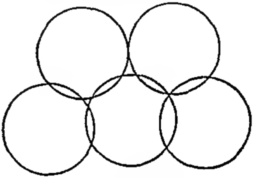
For the treatment of ringworm the use of 100 K.V., a focus skin distance of 20 cm., and an aluminium filter of 1 mm., is recommended. With a current of 2.5 M.A., the exposure will be 3 to 3½ minutes per area. Five areas are exposed and the hair may be expected to fall out after two weeks. Epilation will be complete after 2½ weeks. Six weeks from the time of exposure will see the beginning of the regrowth of hair, and the normal appearance will be re-established after about three months.

It is noteworthy that all chromoradiometers are based on the epilation dose, i.e., that quantity of X rays which will cause the hair to fall out. The widest application of X rays in the early days of skin therapy was for ringworm and very careful dosage is necessary because a slight excess of radiation will cause not only erythema, but permanent baldness. This was noticed at an early date. Later on it was found that small doses applied to bald patches in alopecia areata caused the hair to grow



ABOUT RIGHT

Fig. 125.



WRONG

Fig. 126.

again. Dr. Thedering reports that as small a dose as 0.2 U.S.D. seems to suffice and must be applied at intervals of one to three weeks till the hair begins to grow again after about six applications.

X rays have proved most useful in acne vulgaris, eczema, seborrhoeic dermatitis, and lichen planus; in sycosis and folliculitis, in anal and vulval pruritus, mycosis fungoides, chronic eczema, psoriasis, and in localized hyperidrosis. (See *Arch. f. Dermatol. u. Syph.*, January, 1924, pages 13–17.)

For the treatment of *malignant* diseases of the skin, the healthy part surrounding the diseased area is efficiently protected with a mask of lead or lead rubber, and 120 to 230 per cent. of the erythema dose is then applied to the diseased area. A high percentage of permanent cures is being obtained with X rays in this class of skin diseases.

The dermatological clinic of the University of Zurich reports that cases of rodent ulcer were successfully cured by using 120 K.V., aluminium filters 3 to 4 mm. thick, and by giving 7 Sabouraud Tint B doses to each case, which correspond under the above conditions to about 2.3 erythema doses. When weaker doses were used the result was not permanent and many cases recurred.

Dr Pirie describes in the *American Journal of Roentgenology*, November, 1924, page 482, how corns can be treated with X rays so that they come off in one piece, leaving soft healthy skin behind, with no vestige of a corn remaining

Only the corn, and *no surrounding tissue*, has to be exposed to the X rays This is accomplished by covering the foot with a sheet of lead in which is punched a hole just large enough to allow the corn to protrude through it Voltages of 90 K V must be used, without a filter, 25 cm focus skin distance, and 4 Sabouraud B doses have to be applied in one sitting If the corn is thin, or has been cut off flat, the dose may be reduced a little About a month after the exposure the corn can be separated whole with a finger nail It would be dangerous to expose a large area to such a dose

SOME HINTS FOR DEEP THERAPY

The term "deep therapy" is descriptive of all treatment by X rays of parts of the body situated below the skin Some years ago it came to mean the particular type of intensive irradiation for gynæcological cases which was practised at Erlangen and which for several reasons was not very popular here It would be well if the term would lose this meaning and would simply stand for "therapy at a depth"

Deep therapy can be divided under two headings

Medium Deep Therapy,

Deep Therapy

Medium Deep Therapy is concerned with a variety of conditions in which the seat of trouble is comparatively near the skin, such as glands (thyroid, thymus, hypophysis, lymphatics), blood, leucocytes, etc The field of work comprises conditions so widely separated as climacteric symptoms, tubercular glands, superficial carcinoma, bronchial asthma, leukæmia, exophthalmic goitre neuritis, etc, to mention but a few. Every year, however, is adding to the variety of such conditions in which X-radiation can be used with more or less success

X rays in medium therapy are not used as a destructive agent pure and simple. They are employed to set up certain biological changes, possibly by causing chemical or electrical changes in, or only a partial destruction of, cells In such work, therefore, small doses applied at intervals seem to be the rule

Deep Therapy, on the other hand, refers to localized conditions in deep-seated organs and is particularly concerned with sterilization of the ovaries, carcinoma of the uterus and the cervix, etc

Here the X rays act as a destructive agent Unless the cells of tumours are actually destroyed, either directly or indirectly, the desired effect is not produced Doses are therefore larger and often applied in fewer sittings

The physical problem is the same one in each case, namely, to cause the particular organ or constituent part of the human body to absorb an adequate amount of X-ray energy For the present it would appear that the wave length of the X-radiation is immaterial so far as the biological effect is concerned (see page 138)

The wave length is only of importance because the deeper the organ is situated

the more penetrating must be the radiation in order that it may arrive at its goal in sufficient intensity without being heavily absorbed before it gets there

This however is the big problem If the seat of the trouble is near the skin a comparatively soft ray will still reach it in sufficient quantity and without being absorbed to a dangerous extent by overlying tissue and skin. A deep-seated organ however calls for very hard rays from which soft rays have been removed if the skin is not to suffer through too much absorption before the proper quantity has been given to the organ *in question*

Several radiologists (Seitz Wintz, Holfelder Jüngling etc.) working in various centres have found that certain biological changes can be produced by definite doses of radiation These can be expressed as percentages of the U.S D (i.e., the dose which produces erythema on the skin of a normal adult between 17 and 60 years of age) Thus

20 to 25 per cent U S D	produces erythema	in an infant	[illegible] to 3 months old
25 to 30	"		4 to 6 "
30 to 35	" "		7 to 12 "
35 to 45		in a child	1 to 2 years old
50 to 60		"	2 to 3 "
60 to 70	" "		4 to 7 "
70 to 80	"		7 to 10
80 to 100		"	10 to 16
100		in an adult	17 to 60 "
110			60 to 70
130			70 to 80
70 to 80		in patients suffering from exophthalmic goitre	
60 to 80		in patients suffering from psoriasis	
60 to 90		" " eczema	
80 to 90		in hypotonic cases	
60 to 90		in patients suffering from diabetes	

50 to 70 per cent U.S D	produces	pigmentation
80		epilation
150 to 180		erythema bullosum
180		ulceration

34 per cent U.S D	will destroy	ovarian follicles
60 to 70	"	sarcoma cells
90 to 110		carcinoma cells
135 "		intestinal tissue
180		muscular tissue
50		tubercular tissue
24	"	the spleen

Though it is denied now that it is possible to determine a dose which will kill *all* carcinoma cells or which will have a *uniform* effect on carcinomas appearing in different parts of the body it is undoubtedly a great advance that the doses with which definite results have been obtained in thousands of cases, can be measured and expressed in such a manner that others may apply the same dose and profit by the large experiences which have already been gained elsewhere

The difficulty consists in applying doses of the strength mentioned above to organs which are 6 to 10 cm below the surface *without injuring the skin the superficial layers and the parts surrounding the organs to be treated* To make a carcinoma of the uterus disappear a dose quite as strong as that which will produce an erythema

on the skin has to penetrate to a depth of 8 to 10 cm below the surface, and owing to the greater distance from the anticathode, and the unavoidable absorption taking place in the supervening tissues the X rays are bound to become steadily weaker before they arrive at these depths To apply such strong doses 6 to 10 cm below the skin, without injuring it, it is necessary to use

1 Electrical apparatus and tubes producing a large quantity of very hard X rays,

2 Suitable filters and a suitable distance between anticathode and skin, so that a high percentage of the surface dose will be available 6 to 10 cm below the surface, and

3 Cross-fire

The Apparatus —The electrical plant for medium deep therapy must consist of some unit *capable of generating 150 K V peak, such as the single valve, the four valve*, or the condenser unit (see Plate I)

For deep therapy 200 K V must be available and this is best obtained from a condenser unit *(see Plate I)*

The high tension generating plants are best placed in separate rooms and the current is brought through the wall into the therapy room The latter should be large and airy and its walls must be X-ray proof The control table is best placed outside the therapy room so that the radiologist or his staff observe the patient through lead glass windows

The tube stand must afford adequate protection from primary radiation for the patient A self protected tube (see page 15) is already sufficiently protected in itself A Coolidge tube on the other hand requires a box lined with lead rubber

Provision for aluminium or copper filters must of course, be made

In addition to this there must be available a selection of cones or pyramids of wood which are lined with lead rubber and closed at the end nearest the body, by a thin piece of wood on which there is no lead rubber They thus serve a threefold purpose They fix the focus skin distance and limit the cone of X rays to a certain skin area and volume of the patient s body The thin piece of wood at the end of the diaphragm serves as a filter to absorb any secondary rays which may start from the metal of the filter Its chief object, however is to keep the surface of the patient s body which is within the applicator, flat so that it cannot bulge into the cone (Fig 127) If any part of the body were to project into the aperture of the frame it would come nearer to the anticathode than the edges and would receive an overdose owing to the shorter distance (Fig 128) The even compression which can thus be applied slightly reduces the depth of the object to be treated moreover, it makes the skin anæmic and so reduces its sensitiveness to X rays by *as much as 50* per cent Under a 4 mm aluminium filter a non compressed skin will develop an erythema after it has absorbed little more than 3 Sabouraud Tint B doses With a well-compressed skin 4½ to 6 such doses have to be given to reach the erythema dose It helps also to prevent the patient from moving and shifting the direction of the cone of rays

It is important that the focus of the anticathode should be exactly above the centre of the diaphragm. In the illustration the dotted line indicates the axis through the centre of the diaphragm and the anticathode should be centred so that the

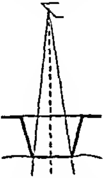


Fig 127

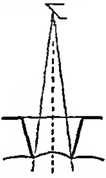


Fig 128.

central ray runs along this line. Fig 129 shows the distribution of the rays over the area to be examined or treated with X rays, when the focus of the anticathode is in the centre above the diaphragm. Fig 130 shows the result when it is not in the centre.

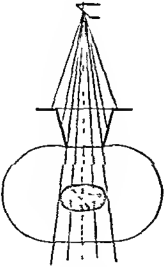


Fig 129

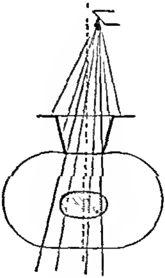


Fig 130.

Concentration of the Rays through various "Windows," or "Cross-fire." —Even the hardest rays which can be used are weakened so much by increasing distance and by absorption, that if 25 per cent of the intensity prevailing at the surface penetrates to a depth of 10 cm. below the skin, this is considered to be a

good ratio with a distance of 23 cm between anticathode and skin and a skin area of about 50 square cm If we were to continue the exposure through the *same part* of the skin, as shown in Fig 131, till a carcinoma of the uterus had received 100 per cent of the erythema dose, the skin would have received about four or five times as much in the meanwhile, and a severe burn with ulcers would be the result, which might be almost as bad as the malignant disease, and equally painful Even the 34 per cent of the erythema dose required for the sterilization of the ovaries would produce ulceration if the whole dose were administered through the same part of the skin

This difficulty can be overcome if the total quantity of X rays to be administered is not allowed to enter through the same part of the skin If the object to be treated is 6 cm or more below the surface a 'cross-fire' can be directed on it from several points of the surface, as indicated in Fig 132, by altering the position of the tube and of the diaphragm after one part of the skin has received about 90 per cent of the

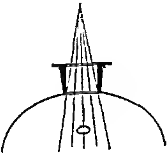


Fig 131

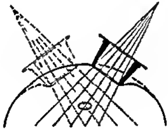


Fig 132

erythema dose If a sufficient number of windows are used, we can apply at a depth of 10 cm doses even greater than the erythema dose without exposing any portion of the skin to more than 90 per cent of the erythema dose

The Number and Size of the Windows to be used depend on the position of the diseased organ, on the dose of rays which we want to apply, and on the ratio between surface intensity and the intensity available at the depth i e , on the percentage depth dose If the latter is, for instance, 20 per cent of the former at a depth of 10 cm , and we wish to apply 100 per cent of the erythema dose to a uterus situated at such a depth, we must use five to seven windows Three of these can be given through the abdomen, a similar number through the back, one might be given from each side, or one through the vulva With the ovaries, the 34 per cent of the erythema dose required to produce sterilization can easily be obtained through two windows for each ovary

Between the adjoining windows, a space of 3 to 4 cm. should be left free, otherwise tissues which are only 1 or 2 cm below the surface may receive an overdose, if the cones of the rays overlap so near the surface that they have not yet been weakened to any large extent by absorption and the greater distance

The Aperture for the Windows should be chosen so that the cone of rays

is large enough not to miss even a small target, like the ovaries, when the direction of the tube has been carefully adjusted, and to include the whole of a malignant tumour, but it should not be unnecessarily large, partly to enable us to find room for a sufficient number of windows on the surface of the abdomen or the back, and partly to avoid exposing an unnecessary quantity of tissues, blood, etc, to the X ray toxin

The tendency is, however, to use larger windows In the first years, when the treatment of excessive hæmorrhage with X rays was begun (1906 to 1910), a large number of windows (up to 50 !) were used occasionally, because with the tubes and apparatus available in those years the percentage depth dose was very small To find room for them, the apertures had to be correspondingly small (about 20 square cm), which resulted in small targets like the ovaries frequently being missed, whilst few tumours can be included entirely in such small cones

For the treatment of malignant diseases, the ideal would be to expose the whole abdomen to a uniform dose of sufficient strength to make the malignant tumours shrink Technically this can be done by giving four exposures with 60 cm distance, one from the front, the second from the back, and one from each side, but when the carcinoma dose is applied to the whole abdomen, the injuries to the blood, etc, become so large that patients are in great danger of succumbing to the X ray poison

Experiments on mice and other animals prove that comparatively large doses produce no visible harm to the general health when administered through a small aperture of 8 mm diam , whereas when the *whole body* was exposed to only one-tenth of this dose, *all* the mice perished, some of them within three hours In the year 1912 or 1913, a few patients, who were *beyond help, were exposed with their consent to large doses over a large area*, with the result that the tumours shrank, but the patients died from the effects of the X ray toxin

A compromise has therefore to be made Windows of 6 × 8 cm have proved to be very convenient in a large number of cases Three of these find room, with the necessary intervals, across the lower part of the abdomen of patients of normal size In the case of stout patients, the apertures may be increased a little, because it is more difficult to find the exact position of the ovaries, etc Apertures of 9 × 9, or even 9 × 12 cm , have to be used if the size of the tumour, or a large distance between anticathode and skin should make it necessary Both ovaries can be exposed simultaneously from the back with a window of 8 × 10 cm at a distance of 30 cm Some doctors prefer windows with an aperture of 80 or even 150 square cm with focus skin distances of from 30 to 40 cm

The percentage of the rays arriving at the depth depends to some extent on the diameter of the cone of rays entering the body, i e, on the size of the window, because the greater it is the more " scattered " rays will be available With a distance of 23 cm between anticathode and skin, we may obtain 20 per cent of the surface dose at a depth of 10 cm when the applicator has an aperture of 50 square cm , when the opening of the applicator is increased to 80 square cm , the intensity of the rays will rise to 23 per cent, and when the aperture is increased to 150 square cm it will rise to about 25 per cent of the surface dose

The losses due to increasing distance and by absorption by the tissues to be traversed—the latter vary with the quality of the rays used—are known, but the

influence of the scattered rays makes it impossible to find by calculation the intensities prevailing at various depths They have to be measured empirically with an Iontoquantimeter or Kienbock strips which may be exposed in a suitable phantom or introduced in cavities like the rectum or vagina of the patient The following figures show the differences existing between calculation and actual measurements

Depth Below Surface in cm	Making Allowance for Absorption and Increasing Distance the Intensities should be	Actual Intensities with Windows of		
		18 × 24	9 × 12	5 7 × 5 7 cm
0	100	100	100	100
5	37 1	45 5	42	40 3
10	10 7	30	24 8	22 6

Correct Distribution of the Dose over the Diseased Area—The dose required to produce sterilization of the ovaries is so small that no harm will be done to the surrounding organs if it should be exceeded 100 or even 150 per cent The matter is totally different when carcinomas have to be treated Fully 100 to 110 per cent of the erythema dose is required to make these tumours shrink, and 140 per cent of the erythema dose may already produce injuries to the bowels so severe that in a few cases they have proved fatal

The result and success of the treatment depend on applying to the diseased area a dose of sufficient strength without injuring any other parts, and this depends to a large extent on whether the direction and sizes of the cones of rays have been correctly chosen Great knowledge, thought and skill are required to do this and a high percentage of the failures with X ray treatment is undoubtedly due to mistakes which have been made in this respect

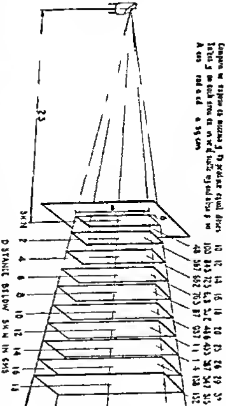


Fig 133

In many cases it will be a great help if a sketch of the cross section of the patient s body is made on paper in natural size and the position and size of the tumour is marked on it as accurately as this can be done Several drawings of the cones of rays, with different sizes of windows should be made on thin celluloid sheets or on transparent paper and the central ray the distance, and the

outlines of the cones should be marked as indicated on Fig 133 By placing one of these transparent drawings over the sketch of the cross section of the body, we can find out whether the size of the cone is large enough to cover the whole of the diseased volume, or whether the size of the window, or the distance between anticathode and skin, should be increased, and what position the tube should have. When a protractor is placed on the drawing the angle which the central ray should form with the perpendicular, and the distance from well known landmarks, like the umbilicus, etc., to the point where it should enter, can be found out. This point is then provided with some mark on the patient s body, and a protractor should also be fixed on the tube stand so that the tube box may be set at the proper angle The illustration (Fig 134) shows what a great difference a slight alteration in the inclination of the tube box may cause to the organs included in the cone of rays

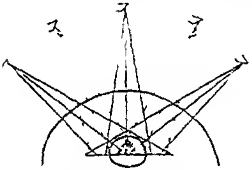


Fig 134

By placing a second transparent drawing over the first, to find the best direction to be given for the exposure through a second or third window, we can see where the cones begin to overlap, and which organs beside the tumour will be subjected to the second or third exposure The direction of the cones has to be chosen so that the *same part* of sensitive organs, like the bowels, should not be included in the cone of rays from too many windows

When the best position for all the windows has been found out, the intensity of the doses to be given to each window has yet to be considered, so *that the sum of* all exposures reaches the intensity we wish to apply to the diseased organ. The farther the X rays penetrate through the tissues of the body, the more uneven will become the distribution of the intensity This is due in part to the losses caused by the greater distance but chiefly to the influence of the scattered rays Their intensity is greatest near the central ray, but diminishes with the square of the distance as the distance *from it increases This intensity also increases within certain limits,* with increasing depth Instead of being distributed evenly over spherical surfaces having their centre at the focus of the anticathode, the surfaces of even intensity gradually assume shapes as shown in Fig 135, but the shape of these curves changes with the penetrating power of the rays with the diameter of the cones of rays used and with the distance between the anticathode and skin

Tables of the distribution of intensity throughout the body have been compiled from measurements made on phantoms under varying conditions of wavelength, focus skin distance, and size of the skin window The results have been plotted on diagrams as shown and the lines represent the edges of surfaces of equal intensity, while the figures denote the percentage depth dose.

Several authors have contributed such diagrams which may be found in a number of publications

They look somewhat bewildering at first and, moreover, there has been a certain amount of discrepancy between the results obtained by various experimenters under similar conditions, but this kind of diagram or table is undoubtedly a help towards obtaining a better understanding of the distribution of the intensities in various regions, and as the success or failure of the treatment of deep seated malignant diseases depends to a large extent on the correct distribution of the necessary intensities over the diseased volume, it is worth while to study them

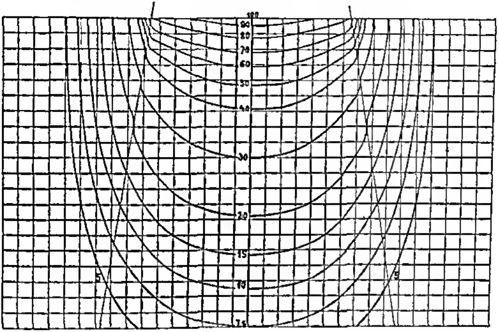


Fig 135

The Distance between Anticathode and Skin also influences the even distribution of intensity throughout a volume of the patient's body at a depth The greater this distance the better will be the percentage depth dose and the smaller will be the difference in the intensities existing at various depths below the skin (see Fig 90 on page 90) In Fig 91A the distance between anticathode and skin is 25 cm, and when the intensity on the skin is equal to 100 units, the intensities prevailing at 4, 6, 8, 10 cm below the skin will be respectively 74, 65, 57, 51 units, so that at a depth of 10 cm below the skin, 49 per cent of the surface intensity dose has disappeared owing to the greater distance from the anticathode If the distance between anticathode and skin were 50 cm, as shown in Fig 90B on page 90, the intensities at 4, 6, 8, 10 cm below the skin would be 86, 80, 74 69 units respectively, so that only 31 per cent is lost at 10 cm below the surface, owing to the greater distance For the even distribution between a depth of, say, 6 to 12 cm, it would therefore be an

advantage always to use large distances but the duration of the exposures will increase rapidly, because four times as large a quantity of X rays will have to be produced with a distance of 50 cm to secure a certain effect, as with a distance of 25 cm only The inconvenience to the patient the loss of time to the operator and the expense of the treatment would be increased very much and a compromise has therefore to be made in this respect. When organs 7 to 10 cm below the skin have to be treated a distance of 23 cm between anticathode and skin is at present considered best.

If the diseased organ is no more than 1 to 5 cm below the skin, as in cases of mammary cancer etc distances as great as 60 or even 100 cm may have to be used to obtain doses of fairly similar intensity at 1 or 3 cm below the skin. The cross fire method is not possible for such cases because the different windows would have to be placed so close together that they would be bound to overlap on the skin, or at any rate immediately below it.

If the distance between anticathode and skin were 23 cm. 50 per cent only of the surface dose would penetrate to a depth of 4 or 5 cm If the exposure were continued till the erythema dose had been obtained at this depth the skin would have received about 200 per cent of the erythema dose, and a severe and painful ulcer would be the result If the exposure were stopped when the surface had received an erythema dose malignant cells 3 to 4 cm below the skin would not have received even the dose which paralyses them They would only have been irritated This may account for some of the failures which have been reported in the treatment of carcinomas of the mammæ the vulva the stomach etc.

The difficulty can be overcome if a greater distance is used between the anticathode and skin and a larger aperture is chosen for the window If the distance is increased to 80 cm and the size of the window to 15 × 12 cm. the percentage of the surface dose which will penetrate to a depth of 3 cm below the surface will increase to 90 and carcinoma cells situated at such a depth can be exposed to the lethal dose without risking any serious injury to the skin

The distance which it is best to use with such cases depends on the thickness of the infected parts and may vary from 50 up to 100 cm The duration of the exposure has to be increased accordingly and may vary from 3 to 10 hours for the full carcinoma dose If the erythema dose can be obtained with a particular tube in 25 minutes at a distance of 23 cm the time required with a distance of 80 cm would be $\frac{25 \times 80^2}{23^2}$ 302 minutes or 5 hours 2 minutes

Since the depth dose increases with the larger size of the window it is necessary to consult the exposure tables given on page 1 6 or to make some experiments on the phantom as described on page 92

Auxiliary Concentrating Filter —A block of paraffin wax 10 cm thick, which is placed between the patient's skin and the ordinary aluminium or copper filter is often used and serves a double purpose In the first place, the drop in intensity of the X rays per centimetre of depth grows less as they penetrate farther into the body A reference to Fig 90 on page 90 will show this at once The difference

in intensity between the skin and 3 cm depth is greater than that between the 9th and the 12th cm The superposition of a 10 cm block of wax has the effect of moving the skin to a point 10 cm deep in the body, and a point 3 cm under the skin is then more nearly at the same intensity as the skin

The second effect is to bunch scattered rays from the wax block into the body as shown in Fig 136, thus increasing the intensity of the available rays

Thus, with a distance of 23 cm between anticathode and skin, the latter, under the wax block, will receive only 20 per cent of an erythema dose in 30 minutes, and in the same time the point 3 cm below the skin receives 17 per cent If the exposure is continued for 2½ hours the skin will have received a full erythema dose and the point 3 cm under it will have had 85 per cent, which is very near the carcinoma dose Thus the relationship between the skin intensity and that at 3 cm depth is as good when the auxiliary filter at 23 cm anticathode skin distance is used as it would be at an 80 cm distance without the filter, but the time which is necessary for the exposure with the filter at 23 cm is only about one third of that required at 80 cm distance

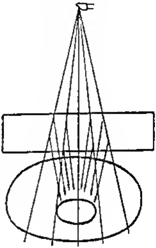


Fig 136

How Long have the Exposures to last?—When it is known in what time an erythema can be produced with a given tube, and what percentage of the surface dose will penetrate to various depths, the duration of the exposures required to produce certain percentages of the erythema dose at various depths can be found out by simple calculations

For instance, if 28 minutes' exposure should be required to produce an erythema and if 26 per cent of the surface dose penetrates to a depth of 8 cm, the total exposure required to obtain 34 per cent of the erythema dose at a depth of 8 cm will be $\frac{28 \times 34}{26} = 36.0$ minutes This would be too much for one window, but with two exposures of 18 minutes' duration each, given through two windows, the dose necessary for sterilization of an ovary can be obtained under the conditions mentioned above, without injury to the skin, 72 minutes total exposure, divided over four windows, would be sufficient to produce the sterilization of both ovaries of a patient of normal size For stout patients about 10 minutes more should be given If one large window is used at the back, instead of two small ones, the time can be reduced a little further

If we wish to apply to a carcinoma 10 cm below the surface a dose of 105 per cent of the erythema dose, and if 20 per cent of the surface dose penetrates to this depth we have to expose under the conditions mentioned above $\frac{24 \times 105}{20} = 126$ minutes In order not to exceed the 28 minutes for one window, six windows will

have to be used, with 21 minutes' exposure through each Stout patients should receive about 3 minutes more through each window, thin patients about 2 or 3 minutes less

If, instead of this, 26 minutes were given through each window, 131 per cent of the erythema dose would reach the region of the uterus, and this is too near the dose which causes injuries to the bowels If we were to expose 16 minutes only, we should obtain 84 per cent of the erythema dose only at the depth of 10 cm., which is a little below the minimum which has been found to be necessary

Strength of Current to be used—This is still a very open question. In the early days of deep therapy the currents ranged from 2 to 5 M.A.—simply because that happened to be the quantity which the apparatus of those days could be counted upon to supply continuously without breaking down Nowadays we have transformers which will give 25 M.A at 150 K.V and 5 to 8 M.A. at 200 K.V continuously, and tubes which will stand up to such loads The question then resolves itself into the one which was discussed on page 135 Radiologists and biologists must find out by continual research and comparison of results whether the single heavy dose heavily applied in one sitting or the many small doses lightly applied with small currents in many sittings is best Opinion seems to be moving considerably in favour of the latter

The X ray Sickness—The symptoms of this are very similar to those of sea sickness, and consist of headache, want of appetite, and in more severe cases vomiting and even diarrhœa, occasionally mixed with blood The severity and duration of the sickness vary a good deal, and depend chiefly on the volume of the body and on the organs which were exposed, on the condition of the patient, and on the duration of the exposure.

The extremities arms and legs are scarcely susceptible, whereas the abdomen and the chest are very sensitive Some patients also suffer a good deal more than others Many patients to whom the sterilization dose has been given in one sitting will escape with a slight headache. Others will suffer from considerable headache for twelve to twenty four hours Others again, will respond with severe X ray sickness

The application of 100 per cent U.S.D to a deep-seated carcinoma is so severe a dose for the whole system that severe sickness and diarrhœa, lasting sometimes for weeks, may result. This is one of the main reasons which is continually urged against the Erlangen technique of huge doses at one sitting In many clinics a preliminary smaller dose is given to test the susceptibility of the patient and also to produce that slight degree of immunity to radiation which enables future larger doses to be more easily borne.

The cause of X ray sickness has not yet been fully explained It has been attributed to the nitric oxide generated by sparks and brush discharges, but this definitely cannot be the case Were it so then radiologists and staff who spend a much longer time in these rooms would suffer in the first instance Undoubtedly, such gases are responsible for lassitude and drowsiness of which assistants often complain and they must be avoided by making the apparatus coronaless (see chapter on Protection), also by providing adequate ventilation.

The sickness of the patient seems to be due to some irritant action of the

rays on the bowels, the stomach, and the blood, which is likely to become overloaded with débris of cells which have been killed by the X rays Besides this, well marked changes are produced in the blood, which can easily be proved with the microscope In particular, the number of leucocytes becomes reduced in proportion to the quantity of X rays which reaches the body With the sterilization dose the blood always recovers its normal composition, so far as this can be proved with the microscope, within three weeks, with the dose required for carcinomas, six or even eight weeks are required before this has taken place The changes in the blood place a limit on the area which may safely be treated with the carcinoma dose at one exposure, otherwise it would be quite possible to expose the whole abdomen to this quantity of rays After the blood has recovered, a second exposure may be given after eight weeks, and a third one after sixteen weeks With some patients, however, the blood seems to have lost the power to recuperate, the vitality has been lowered too far already by the malignant disease With most of these the X ray treatment proved fruitless, and though the tumours may have disappeared, they succumbed With a few, transfusion of the blood has been carried out successfully, they recovered, and are in good health

Dr Holzknecht, of Vienna, the well known pioneer of X ray science, reported recently that an injection of 10 c c of a 10 per cent solution of salt into the veins makes the symptoms of the X ray sickness disappear within about an hour He was led to try salt, because the blood of patients suffering from this sickness contains less than the normal quantity of salt His experience has already been confirmed since by several others, who have also given 5 grm of salt in tabloid form

Injuries and Accidents —As many thousand X ray exposures are made every day, it is not surprising that a large number of injuries have already been caused The more severe injuries and some fatal accidents are more or less confined to therapeutic exposures, but slighter injuries are frequent enough even with diagnostic examinations

Over exposures which are responsible for most injuries may be due to a variety of causes Thus, for instance, want of knowledge and experience in determining the correct dose, errors in measuring the quality and quantity of the rays used, or mistakes in measuring the focus skin distance or making correct allowance for any change of it, will all cause an incorrect dose to be applied More serious faults are the omission to insert the filter, and the omission to switch the current off at the intended time, if, for instance, the operator has more than one patient to attend to, or other duties to carry out, while the exposure is going on Then again excess dosage will arise by an accidental exposure of the same part of the skin for a second time, or by allowing too short a period of rest after a previous exposure It is essential that eight weeks should be allowed to any part of the skin which has been exposed to a full erythema dose, and four weeks and two weeks for half or quarter of such a dose respectively. Moreover, a patient who has been exposed a few weeks or months previously to X rays somewhere else, will be unusually sensitive to the rays The same applies to patients who have inflammation of the skin or who have used ointments or medicines containing mercury, zinc, bismuth, iodine, etc, or who are suffering from diseases such as nephritis, syphilis, diabetes, etc

Errors in adjusting the direction and position of the tube, so that the cones of rays overlap and that the *same* part of sensitive organs like the bowels are included too frequently in the cone of rays, may cause stenosis or even rupture, and peritonitis may be the result The bladder, the larynx, and the brain are also very sensitive to over exposures Fluctuations in the supply of current from the main may also be responsible, though they lead more frequently to an under than to an over-exposure

Injuries occasionally appear as late as a year or even several years after the exposure The vitality of the epidermis or the epithelial cells may have been lowered, and the skin then remains very sensitive to subsequent mechanical injuries pressure, friction, or irritation by chemicals Irritant soap has repeatedly been traced as the cause of late injuries appearing One case is recorded in which a surgeon spilled a little hydrochloric acid over his left hand, and an X ray dermatitis appeared a year afterwards, but was confined to that part of the skin only which had been in contact with the acid for half a minute, the other parts of the skin remained healthy, though they had been exposed to the same small doses of X rays

The degree of the injuries varies with the degree of over-exposure and *with the area which has been exposed* Even a serious over-exposure confined to a small area will do less harm than a comparatively small over-exposure spread over a large area A case is reported in which the filter was forgotten, and an area of about 12 square cm. received fully five erythema doses, but no ulcer followed The locality of the over-exposure is also important.

Organs which are normally exposed to great wear and tear, like the feet, the hands, the anus etc., are very susceptible in this respect The anus is exposed to pressure, friction and chemical irritation by the fæces, and the soles of the feet to constant pressure in walking A case is recorded in which the leg had to be amputated ultimately after the foot had been exposed to X rays of moderate intensity, for eight minutes only, for treatment of an eczema The hands of numerous X ray operators are a proof of the severe injuries which may follow exposures to weak but often repeated doses but it has to be remembered that practically *all* these injuries were caused in the first years when the toxic effects of the X rays were not known, when the hands of the operators were invariably held between tube and screen to determine the quality of the rays or for demonstrations, and when no protecting boxes round the tubes were known If such injuries are caused nowadays it is certainly due to great carelessness

All sorts of ointments have been tried in vain as remedies, but pain can be reduced and the process of healing favourably influenced by applying warm moist compresses or diathermy, to stimulate the circulation of the blood over the injured area

There is unfortunately no doubt that carelessness, and want of knowledge, skill, and experience in the application of X rays, have claimed numerous victims already, but the benefits which mankind derives from the X rays are infinitely greater, and the latter will go on increasing, and the number of mistakes and accidents will become smaller, as the methods of measuring the dosages and of applying the X rays correctly become better known

CHAPTER X

PROTECTION

In the practice of radiology the patient and the operating staff are exposed to dangers from two sources, and it is the first duty of everyone who uses X rays to minimize these risks as far as possible

The two sources are the X rays themselves and the high tension currents which go to produce them

X rays affect the cells of the human body, and this fact, which was discovered soon after the rays themselves, forms the basis of all X ray therapy Properly controlled in regard to quality and quantity, X radiation does much good, but excessive exposure to it gives rise to erythema, dangerous burns not unlike cancer, and to sterility, damage to blood, etc Moreover, the effects of X rays are cumulative, so that, though individual patients receive doses which are not harmful, radiologists who are not carefully protected will suffer, through exposure to small doses spread over weeks or months or even years

The physiological effects of high tension current are muscular contraction, extreme shock, and immediate death if the voltage is sufficiently high and the duration of contact sufficiently long

The risks are avoided by preventing both the primary beam and the scattered rays from reaching the operating staff at all, and by reducing the amount which reaches the patient to a minimum Risks of shock and accident from electric currents are avoided by arranging that all leads and parts of apparatus which carry high tension cannot be touched unintentionally, whilst all other parts of apparatus must be earthed so that they are at the same electrical potential as the human beings around them

There was much difference of opinion as to the best form which protection should take, and an X ray and Radium Protection Committee was formed in England some fourteen years ago, to investigate the whole problem This body issued two reports containing a series of recommendations, and in 1928 had the satisfaction of seeing them accepted as a basis by all countries at the Second International Congress of Radiology in Stockholm

The points of the Committee's work which concern us here are the following —

1 The dangers of over exposure to X rays and radium can be avoided by the provision of adequate protection and suitable working conditions It is the duty

of those in charge of X ray and radium departments to ensure such conditions for their personnel. The known effects to be guarded against are —

a Injuries to the superficial tissues

b Derangements of internal organs and changes in the blood

I Working Hours, Etc

2 The following working hours, etc, are recommended for whole-time X ray and radium workers —

a Not more than seven working hours a day

b Not more than five working days a week The off-days to be spent as much as possible out of doors

c Not less than one month's holiday a year

d Whole time workers in hospital X ray and radium departments should not be called upon for other hospital service.

II. General X Ray Recommendations

3 X ray departments should not be situated below ground floor level

4 All rooms, including dark rooms should be provided with windows affording good natural lighting and ready facilities for admitting sunshine and fresh air when ever possible

5 All rooms should be provided with adequate exhaust ventilation capable of renewing the air of the room not less than ten times an hour Air inlets and outlets should be arranged to afford cross wise ventilation of the room.

6 All rooms should preferably be decorated in light colours

7. X ray rooms should be large enough to permit a convenient lay-out of the equipment. A minimum floor area of 250 square feet (25 square metres) is recom mended for X ray rooms and 100 square feet (10 square metres) for dark rooms. Ceilings to be not less than 11 feet (3 5 metres) high.

8 A working temperature of about 18° C. (65° F) is desirable in X ray rooms

9 Wherever practicable the X ray generating apparatus should be placed in a separate room from the X ray tube

III X Ray Protective Recommendations

10 An X ray operator should on no account expose himself unnecessarily to a direct beam of X rays

11 An operator should place himself as remote as practicable from the X ray tube and, if possible, in the "shadow" of the target. It should not be possible for a well rested eye of normal acuity to detect in the dark appreciable fluorescence of a screen placed in the usual position of the operator

12 The X-ray tube should be surrounded as completely as possible with protective material of adequate lead equivalent

13 The following lead equivalents are recommended as adequate —

X Rays Generated by Peak Voltages.	Minimum Equivalent Thickness of Lead
Not exceeding 75 K V	1 mm
,, ,, 100 ,,	1 5 ,,
,, ,, 125 ,,	2 ,,
,, ,, 150 ,,	2 5 ,,
,, ,, 175 ,	3 ,,
,, ,, 200 ,,	4 ,,
,, ,, 225 ,,	5 ,,

14 In the case of radiography, the operator should be afforded protection from scattered rays by a screen of a minimum lead equivalent of 1 mm

15 In the case of X ray treatment the operator is best stationed completely outside the X ray room, behind a protective wall of a minimum lead equivalent of 2 mm This figure should be correspondingly increased if the protective value of the X ray tube enclosure falls short of the values given in paragraph 13 In such event the remaining walls, floor, and ceiling may also be required to provide supplementary protection for adjacent occupants to an extent depending on the circumstances

16 Screening examinations should be conducted as rapidly as possible with minimum intensities and apertures

17 The lead glass of fluorescent screens should have the protective values recommended in paragraph 13

18 In the case of screening stands the fluorescent screen should, if necessary, be provided with a protective ' surround," so that adequate protection against direct radiation is afforded for all positions of the screen and diaphragm

19 Screening stands and couches should provide adequate arrangements for protecting the operator against scattered radiation from the patient

20 Inspection windows in screens and walls should have protective lead values equivalent to that of the surrounding screen or wall

21 Efficient safeguards should be adopted to avoid the omission of a metal filter in X ray treatment

22 Protective gloves, which should be suitably lined with fabric or other material, should have a protective value not less than ½ mm lead throughout both back and front (including fingers and wrist) Protective aprons should have a minimum lead value of ½ mm

IV Electrical Precautions in X Ray Rooms

23 The floor covering of the X ray room should be of insulating material, such as wood, rubber, or linoleum

24 Permanent overhead conductors should be not less than 9 feet (3 metres) from the floor They should consist of stout metal tubing or other coronaless type of conductor The associated connecting leads should be of coronaless wire kept taut by suitable rheophores

25 Wherever possible earthed guards should be provided to shield the more adjacent parts of the high tension system Metal parts of the apparatus and room should be efficiently earthed, unless there are reasons to the contrary

26 The use of quick acting double pole circuit breakers is recommended Over powered fuses should not be used If more than one apparatus is operated from a common generator, suitable overhead multi way switches should be provided

27 Some suitable form of kilovoltmeter should be provided to afford a measure of the voltage operating the X ray tube

In radiotherapy the same recommendations of course hold good, but they are generally applied in a different way The tube is surrounded, as before, by a protective box so that the primary beam is localized for the protection of the patient. The operator, on the other hand, is protected from scattered rays by being placed outside the therapeutic room or cubicle in which the patient is treated The walls, floor, and ceiling are of material with the requisite lead equivalent, and the patient is observed through a lead glass window

In connection with the above recommendations some work by Glocker should be noted in which he measured the lead equivalent of a number of substances used in building, etc (see also Table XXIII, page 181)

He found that the thickness of the several materials detailed below which has a lead equivalent of 1 mm is —

Lead rubber		3 mm	Barium slabs	14 mm
„ glass	(1923)	9 „	Bricks	116 „
„ „	(1926)	4 „	Cement	62 „

From this it becomes apparent that the walls, floors, and ceilings of modern ferro-concrete buildings afford more protection than was at one time thought to be the case, and perhaps the use of barium in cement does occasionally err too much on the side of precaution In view of the cost of such cement or barium blocks, this point wants careful consideration by those responsible for designing X ray departments

Turning to the question of apparatus design, we are faced with two problems We must wholly enclose the tube in protective material with the requisite lead equivalent. Moreover, we must guard against scattered radiation

In Fig 137 we see the elevation of a couch and the elevation and plan of a screening stand in which gas or Coolidge hot cathode tubes are employed A protected box wholly encloses them, so that the primary beam is confined to its proper place The scattered rays, however, which emerge from all matter traversed by the primary beam can freely penetrate the operator

In Fig 138 we see the devices which have been adopted to guard the operator against scattered radiation A lead collar is fixed on the front of the tube box to stop scattering in the air Every couch is fitted with a lead screen at the side, and

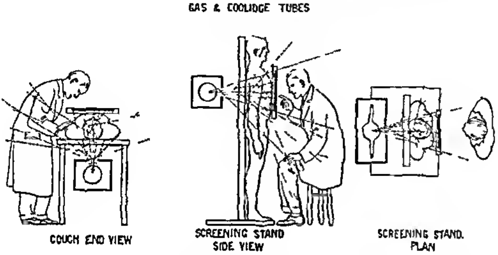


Fig 137

to the fluorescent screens of screening stands a lead rubber apron is hung In addition, two side wings or curtains of lead rubber are hung on the front of screening stands, so that students and observers standing on either side of the radiologist are also safe from scattered rays

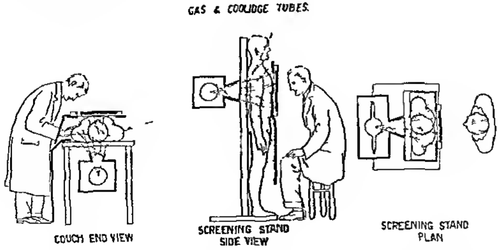


Fig 138

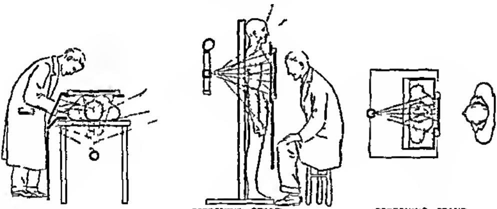
These precautions have led, during the last few years, to a complete re-designing of diagnostic appliances The light and flimsy couch and screening stand have given [illegible] which are strong enough to support the weight both of the totally

enclosing tube box and of the additional lead protection against scattered radiation

The coming of the Self protected tube (see page 15), has altered matters somewhat Not only is the wholly enclosing protective box unnecessary, but it is undesirable for reasons which have been explained on page 16

We must not, however, assume that we can now return to the light and simple couches and screening stands which were formerly in use Certainly the big tube boxes are not wanted any more where Self protected tubes are used, but X rays from such tubes are scattered in just the same way by air or by the patient's body, as the rays from gas or Coolidge tubes The couch for a Self protected tube must, therefore, still be provided with the lead screen at the side, and the screening stand must still have the lead rubber side wings, the lead glass on the fluorescent screen, and the lead rubber apron hanging from it Without these accessories the couches and screening stands are not safe, and in Fig 139 we see, diagrammatically, how the Self protected tube acts

SELF PROTECTED TUBE



COUCH END VIEW

SCREENING STAND SIDE VIEW

SCREENING STAND PLAN

Fig 139

as its own protective box, and how it must be used on couches and screening stand which protect the operator from scattered rays in the same way as when other X ray tubes are used

There has from time to time been a considerable amount of criticism of these recommendations Some radiologists have chafed under the restrictions upon free movement which result from them, saying that actual dermatitis is avoided by much less precaution than that recommended, whereas late effects due to action on the blood etc, are not yet proved Some manufacturers, on the other hand, have complained that costs of production become so high when the recommendations are complied with, that potential users are frightened by prices and go to less conscientious producers who pooh pooh the whole business

To these doubting voices one can only reply that though the question of late and accumulated after-effects requires further investigation, there is quite enough

evidence of far reaching change of long duration to warrant considerable precaution Secondly, the recommendations of the Committee, drawn up on exact physical facts are only recommendations It is open to any biologist who cares to take the responsibility, either from statistics or from experiment, to put forward alternative suggestions, and to this end the subject was reviewed again at the International Congress in Paris in 1931 Thirdly, the recommendations are now an international basis and the fact that other countries have felt the need to follow where Britain led, is in itself evidence that our Committee is on the right track

Meanwhile, the recommendations tell us what precautions render us quite safe To ignore them is to court disaster To reduce them is to take a risk the magnitude of which we do not know

CHAPTER XI

TABLES

In order to facilitate reference there are collected together in this chapter the most important of the tables which appear throughout this book. Added to these are a few more which may be of interest and help to the radiologist in his work. The data have been compiled as carefully as possible from current literature, and it is hoped that errors have been reduced to a minimum. The author would be grateful to receive news of any corrections which may prove to be necessary.

GENERAL TABLES

No I

ATOMIC NUMBERS, SYMBOLS AND WEIGHTS.

Atomic Numbers	Name	Symbol	Atomic Weight	Atomic Numbers	Name	Symbol	Atomic Weight
1	Hydrogen	H	1·008	41	Niobium	Ni	93.5
2	Helium	He	4	42	Molybdenum	Mo	96·0
3	Lithium	Li	6·94	43	—	—	—
4	Beryllium	Be	9·02	44	Ruthenium	Ru	101·7
5	Boron	B	10·9	45	Rhodium	Rh	102·9
6	Carbon	C	12·0	46	Palladium	Pd	106·7
7	Nitrogen	N	14·0	47	Silver	Ag	107·9
8	Oxygen	O	16·0	48	Cadmium	Cd	112·4
9	Fluorine	F	19·0	49	Indium	In	114·8
10	Neon	Ne	20·2	50	Tin	Sn	118·7
11	Sodium	Na	23·0	51	Antimony	Sb	121·8
12	Magnesium	Mg	24·3	52	Tellurium	Te	127·5
13	Aluminium	Al	27·1	53	Iodine	I	126·9
14	Silicon	Si	28·3	54	Xenon	Xe	130·2
15	Phosphorus	P	31·0	55	Caesium	Cs	132·8
16	Sulphur	S	32·0	56	Barium	Ba	137·4
17	Chlorine	Cl	35·5	57	Lanthanum	La	138·9
18	Argon	A	39·8	58–71	Rare earths	—	—
19	Potassium	K	39·1	72	Hafnium	Hf	178·8
20	Calcium	Ca	40·0	73	Tantalum	Ta	181·5
21	Scandium	Sc	45·1	74	Tungsten	W	184·0
22	Titanium	Ti	48·1	75	—	—	—
23	Vanadium	V	51·0	76	Osmium	Os	190·9
24	Chromium	Cr	52·0	77	Iridium	Ir	193·1
25	Manganese	Mn	54·9	78	Platinum	Pt	195·2
26	Iron	Fe	55·8	79	Gold	Au	197·2
27	Cobalt	Co	58·9	80	Mercury	Hg	200·6
28	Nickel	Ni	58·7	81	Thallium	Tl	204·4
29	Copper	Cu	63·5	82	Lead	Pb	207·2
30	Zinc	Zn	65·3	83	Bismuth	Bi	209·0
31	Gallium	Ga	69·9	84	Polonium	Po	210·0
32	Germanium	Ge	72·5	85	—	—	—
33	Arsenic	As	74·9	86	Radon	Nt	222·0
34	Selenium	Se	79·2	87	—	—	—
35	Bromine	Br	79·9	88	Radium	Ra	226·0
36	Krypton	Kr	82·9	89	Actinium	Ac	?
37	Rubidium	Rb	85·4	90	Thorium	Th	232·1
38	Strontium	Sr	87·6	91	Protactinium	Pa	?
39	Yttrium	Y	89·3	92	Uranium	U	238·2
40	Zirconium	Zr	90·6				

No. II.

Wave Lengths of Various Rays.

Rays.				Wave Length.
Wireless or Hertzian	..		..	20 kilometres to 2 millimetres.
Heat ..	..	..	..	3000 $\mu\mu$ to 720 $\mu\mu$ (= 7200 A.U.)
Visible	..	..	..	7200 A.U. to 4000 A.U.
Ultra Violet	..	..	..	4000 A U. to 2000 A.U.
X Rays	..	..	..	500 A.U. to 0 06 A.U.
γ Rays	..	..	..	1 4 A.U. to 0 01 A.U.

No. III.

Kilovoltage—Spark Gap—Boundary Wave Length.

Tension	Spark Gap in Cm.			Boundary Wave Length in A U.
K.V. (peak)	Point Plate	5 cm Spheres	10 cm. Spheres	
30	—	0 0	0 0	0 414
40	5 0	1 3	1 3	0 310
50	7 2	1 7	1 0	0 248
60	0 4	2 2	2 0	0 200
70	11 2	2 7	2 4	0 177
80	13 0	3 3	2 8	0 155
00	15 0	3 0	3 3	0 138
100	17 0	4 8	3 7	0 124
110	19 0	5 8	4 2	0 112
120	21 0	7 1	4 8	0 103
130	23 0	8 7	5 4	0 095
140	25 5	—	6 0	0 088
150	27 5	—	0 0	0 082
160	30 0	—	7 4	0 077
170	32 0	—	8 2	0 073
180	34 0	—	9 0	0 069
100	36 0	—	10 0	0 065
200	38 0	—	11 0	0 062

No. IV.

Variation of Intensity or Time of Exposure with Distance.

If I_d is the intensity of radiation as measured by some form of intensity meter at a distance d from the focus of the tube, then the intensity I_x at some other distance x under otherwise similar conditions will be :—

$$I_x = I_d \times \frac{d^2}{x^2}$$

If t_d is the time of exposure which is necessary to produce a certain effect at a distance d from the focus of the tube, then the time t_x which is necessary to produce the same effect at some other distance x under otherwise similar conditions will be :—

$$t_x = t_d \times \frac{x^2}{d^2}$$

No. V.

Tensions Necessary to Excite Characteristic K Rays in Certain Elements.

Element	Tension in K.V. (peak) Optimum	Minimum
Hydrogen	0 003	—
Carbon	0 410	0 29
Oxygen	—	0 52
Aluminium	—	1·5
Iron	9 0	7·1
Copper	11·1	8 9
Zinc	11·3	9 5
Silver	33 0	25 7
Tungsten	95 0	70 0
Platinum	108 0	78 0
Lead	120 0	90 0

No. VI.

Comparison of the Old Description of X-ray Penetrating Power in Equivalent Spark Gaps with the Modern Kilovoltage Notations.

Description	Old Equivalent Spark Gap Point Plate in cm.	New K.V. Peak
Very soft	3–4	20–30
Soft	4–6	30–45
Medium soft	6–15	45–90
Medium hard	15–22	90–120
Hard	22–30	120–160
Very hard	30–40	160–210

TABLES FOR DIAGNOSIS

No. VII.

Exposure Table.

The following table gives the number of seconds of exposure which are necessary for various parts of the body at various voltages when :—

1. We use a hot cathode and one milliampère of current.
2. The current is obtained from a closed core transformer with or without rectifier.

3 The distance from tube focus to film is 26 inches, i e, that which is used for Potter Bucky work

4 The patient is a normal adult of about 12 stone weight

5 Two intensifying screens are employed

6 No Potter Bucky diaphragm is used

For instructions for use, see p 105

Peak kilovoltage	50	55	60	70	85	100	110
Head (back to front)	—	—	—	—	40	31	27
Head (lateral)	—	—	—	36	21	17	14
Teeth	14	8	6	—	—	—	—
Spine (cervical)	—	—	34	18	11	8	—
Shoulder	—	—	25	15	8	6	—
Elbow	—	29	19	11	8	4	—
Wrist	21	13	8	5	—	—	—
Hand	16	12	8	4	—	—	—
Fingers	8	6	—	—	—	—	—
Lungs	31	18	13	8	4	2	—
Stomach (meal)	—	—	30	17	10	7	8
Spine (dorsal)	—	—	—	30	17	12	11
,, (lateral)	—	—	—	—	36	27	23
Kidney Gall bladder	—	—	—	40	25	18	16
Spine (lumbar) Pelvis	—	—	—	—	30	21	18
Knee Joint	—	—	21	13	8	6	4
Leg	—	21	15	8	5	2	—
Ankle Foot	26	16	10	6	4	—	—

No VIII

Metol Developer Formula

3	grammes	Metol
90	,,	Anhydrous sodium sulphite (or 180 grammes crystalline)
7	,,	Hydroquinone
50	,,	Potassium carbonate
5	,,	Potassium bromide

These chemicals are dissolved in the order in which they appear above, in 500 c c of tepid (preferably distilled) water The solution is then made up to 1 litre and employed undiluted

No IX

Acid Fixing Bath Formula

1000	c c	Water
200	grammes	Crystalline sodium hyposulphite
60	,,	,, ,, sulphite
60	,,	,, chrome alum
10	,,	30 per cent acetic acid

No. X.

Effect of Temperature on Time of Development.

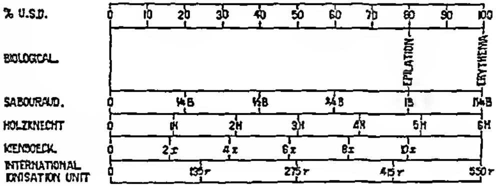
	12°	14°	16°	18°	20°	22°	24°	Centigrade
Metol Hydroquinone ..	16	10	7	5	4	3½	3	Minutes
Glycin 1 : 4	30	27	24	21	18	15	12	,,
Rodinal 1 : 10 ..	10	6	4½	3½	3	2½	2	,,

TABLES FOR THERAPY

No. XI.

Comparison of Various Dosage Meter Readings in Soft Unfiltered Radiation

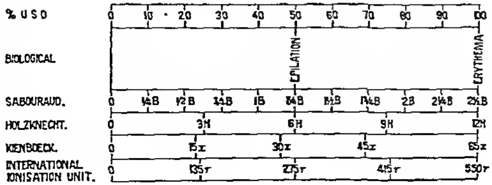
UNFILTERED RADIATION.



No. XII.

Comparison of Various Dosage Meter Readings in Hard Filtered Radiation.

0·5% Cu FILTERED RADIATION.



No XIII

Variation of Skin Dose when the Ratio of Focus Pastille Distance to Focus Skin Distance is Varied

Fractional Doses

In order that a Sabouraud B tint may indicate

100%	80%	60%	40%	20% U S D on the skin,

make the focus skin distance equal to

2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$4\frac{1}{2}$ times the focus

pastille distance See also fig No 87 on page 83

Multiple Doses

In order that a Sabouraud B tint may indicate

100 per cent	150 per cent	200 per cent,

make the focus skin distance equal to

2	1 5	1 4 times the focus

pastille distance See also fig No 88 on page 83

No XIV

Approximate Relationship between Copper and Aluminium Filters

The relation between aluminium filters and filters of copper is as follows —

0 1 mm of copper absorb about as much as 2 5 mm of aluminium
0 2 mm „ „ „ 5 mm „
0 3 mm „ „ „ 7 5 mm „
0 4 mm „ „ „ 10 mm „
0 5 mm „ „ „ 12 5 mm „
1 0 mm „ „ „ 25 mm „

No XV

Which Wave Length in the X-Ray Spectrum has Maximum Intensity at Certain Tensions and Filters? (Holzknecht)

Tension K V Peak	Filter Cu mm	Filter Al mm	Most Intense Wave Length	Corresponds to [K V Peak]
230	1 0	1	0 14	88
230	0 5	1	0 15	83
200	0 5	1	0 16	77 5
175	0 5	1	0 17	73
150	0 5	1	0 18	69
150	—	6	0 22	56
140	—	4	0 23	54
125	—	1–2	0 26	48
125	—	0 5–1	0 27	46

Nos XVI–XX

Percentage Depth Dose

Tables Nos XVI–XX refer to the percentage of the surface intensity which will be available at various depths below the surface

This depends on—

1 The quality of the radiation as given by
   a The boundary wave length, or tension reading
   b The filter
2 The size of window on the skin
3 The depth below the surface of the object to be treated
4 The anticathode-skin distance

In Table XVI we have the percentage of the surface intensity which is available at 10 cm below the surface for various wave lengths or kilovoltages and various filters, when a window 6 × 8 cm and an anticathode skin distance of 50 cm are employed The tensions vary from 73 K V to 138 K V (tables for higher tensions are in preparation) and the filters from 0 2 to 1 0 mm of copper—there being added a constant 2 mm of aluminium Thus, if our radiation is generated by 95 K.V. (peak) or has a boundary wave length of 0 13 A.U and we use a filter of 0 5 mm zinc + 2 mm aluminium, the depth dose under the above condition is 28 3 per cent. We will call this D_1

No XVI

Tension in K V (peak)	λ_0 in A U	F mm. Zn + 2 mm. Al								
		0 2	0 3	0·4	0 5	0 6	0 7	0 8	0 9	1 0
138	0 09	25 5	28 2	30 5	32 5	34 2	35 5	36 6	37·0	37 4
124	0 10	24 5	27 2	29 5	31 5	33 2	34 4	35 5	36 1	36 4
112	0 11	23 6	26 3	28 6	30 4	32 2	33 5	34 6	35·0	35·4
103	0 12	22 6	25 4	27 7	29 4	31 1	32 5	33 5	34 0	34 4
95	0 13	21 8	24 5	26 8	28 3	30 1	31 5	32 5	33·0	33 4
88	0 14	20 9	23 6	25 8	27 3	29 1	30 5	31 5	32·0	32 4
82	0 15	20 0	22 7	24 8	26 2	28·0	29 5	30 5	31 0	31 4
77	0 16	19 2	21 9	23 8	25 2	27 0	28 5	29 4	30·0	30 4
73	0 17	18 4	21 0	22 8	24 1	25 9	27 6	28 4	29 0	29 4

Table XVII gives the variation of the percentage of the surface intensity available at a depth when we vary the size of the window

From Table XVI or from our Kienbock or Iontoquantimeter experiment, we have found the percentage depth dose D_1 under the conditions mentioned above In Table XVII we find what this percentage becomes when the area of the window (E) is changed from $6 \times 8 = 48$ sq cm to something else Thus if $D_1 = 28$ per cent at 48 sq cm window, it becomes 31 7 per cent when the window area is increased to 8×10 cm $= 80$ sq cm We call this new percentage D_2

Tables XVIII, XIX, XX give the variation of the percentage depth dose, D_2, when the depth of the object (d) and the anticathode-skin distance are changed D_2 is the depth dose at 50 cm anticathode-skin distance and 10 cm depth of object Table XVIII gives the values for anticathode skin distance of 25 cm, Table XIX for 30 cm, and Table XX for 40 cm Each of these tables gives the variation for varying depth of object

Thus, if our anticathode skin distance becomes 25 cm and the depth of object 7 cm, the percentage depth dose, D_2 (31 7 per cent), becomes (see Table XVIII) 33 per cent. If, however, the anticathode-skin distance is 30 cm and the depth of object 12 cm, the value of D_2 (31 7 per cent) becomes (see Table XIX) 21 4 per cent

No XVII

Effect of Area of Skin Window on Depth Dose

D_1 / r	18%	19%	20%	21%	22%	23%	24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%
20	0.3	10.2	10.9	11.6	12.4	13.2	14.0	15.0	10.0	17.1	18.0	10.3	20.0	21.5	22.6	23.6	24.7	25.7	20.8	27.0
30	12.0	13.8	14.0	15.5	10.7	18.8	10.8	20.5	21.3	22.1	23.0	24.2	25.5	26.0	27.5	29.3	30.3	31.8	33.0	34.8
40	10.1	17.0	17.9	18.8	19.8	26.8	21.9	22.7	24.0	25.1	25.9	20.9	28.0	20.2	30.3	31.3	32.4	33.5	34.5	39.5
50	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	20.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0
60	20.0	20.0	21.8	22.7	23.7	24.0	25.5	26.5	27.5	28.5	29.5	30.5	31.4	32.4	33.3	34.2	35.0	30.0	37.1	38.1
70	21.1	22.1	23.0	24.0	24.0	25.8	26.7	27.7	28.7	29.7	30.0	31.0	32.5	33.5	34.2	35.2	30.0	37.1	38.0	33.0
80	22.3	23.2	24.2	25.2	20.2	20.0	28.0	28.9	30.0	30.9	31.7	32.7	33.0	34.5	35.2	30.2	37.2	38.2	30.0	30.7
90	23.0	24.0	25.0	29.0	20.9	27.7	28.8	29.7	30.7	31.7	32.7	33.3	34.4	05.3	30.1	37.1	38.3	30.0	39.0	10.4
100	23.9	24.0	25.8	26.8	27.5	28.5	20.0	30.5	31.4	32.5	33.7	34.0	35.2	39.2	37.1	38.0	30.0	39.8	40.2	41.2
110	24.3	25.3	20.2	27.4	28.2	29.2	30.1	31.1	32.2	33.2	34.3	34.8	36.0	37.0	38.0	38.7	39.0	40.4	41.0	42.1
120	24.7	25.7	20.7	28.0	20.0	30.6	30.7	31.7	33.0	34.0	34.0	35.7	30.8	37.8	38.8	39.5	40.2	41.0	41.8	43.0
130	25.5	26.5	27.5	28.5	29.5	30.5	31.3	32.3	33.5	34.5	35.5	30.2	37.2	38.2	30.0	40.0	40.8	41.5	42.4	43.5
140	26.4	27.4	28.4	29.0	30.0	31.0	32.0	33.0	34.0	35.1	36.0	30.8	37.6	38.5	39.2	40.6	41.5	42.0	43.1	44.0
150	26.6	27.7	28.0	29.3	30.2	31.2	32.3	33.4	34.4	35.3	30.3	37.0	37.8	38.7	39.5	40.0	41.6	42.3	43.4	44.3

No. XVIII.—FOCUS SKIN DISTANCE FS = 25 cm.
EFFECT OF FOCUS SKIN DISTANCE ON DEPTH DOSE.

d \ D_1	10%	12%	14%	18%	18%	20%	22%	24%	23%	28%	30%	32%	34%	38%	38%	40%	42%	44%
1	72.4	73.8	75.1	70.1	76.4	70.7	77.1	77.6	80.7	81.3	82.1	82.8	83.5	84.5	85.6	85.7	85.9	86.2
2	58.4	60.2	61.4	62.1	63.4	64.1	65.0	05.0	60.9	08.0	08.8	69.7	70.7	71.8	72.5	73.5	74.8	75.7
3	46.3	47.6	48.6	50.0	50.5	51.6	51.9	52.0	54.3	55.8	56.6	57.0	58.8	66.6	60.9	62.1	63.5	64.4
4	30.4	38.4	39.5	46.7	41.6	42.1	43.1	44.4	45.8	47.0	48.2	49.7	50.7	51.8	53.1	53.6	56.6	57.4
5	20.2	36.6	62.1	33.8	34.1	35.1	36.1	37.4	38.0	39.3	30.4	39.6	41.3	42.0	43.8	40.5	40.2	51.6
8	22.0	24.6	25.8	27.6	28.3	30.6	62.6	33.5	34.0	34.4	30.0	37.6	38.4	36.6	40.0	42.7	43.0	45.6
7	17.5	10.8	20.8	22.2	23.6	24.4	25.8	27.2	28.8	30.1	31.5	33.6	34.5	35.9	37.3	38.0	30.9	11·1
8	16.8	15.2	16.7	18.2	19.1	20.6	22.3	23.0	25.4	26.6	28.2	29.4	31.0	32.4	33.9	35.0	07.7	08.6
9	16.1	11.6	13.1	14.0	15.7	17.3	18.6	20.3	21.6	23.4	24.7	20.2	27.7	29.2	30.5	31.0	33.5	34.8
10	7.3	8.8	10.3	11.7	13.2	14.0	10.0	17.5	16.1	20.6	22.0	23.4	25.6	26.4	28.6	29.3	30.8	32.2
11	5.3	7.1	8.1	0.6	11.6	12.2	13.0	15.1	16.7	18.0	18.9	20.3	21.8	23.3	24.8	26.2	28.6	30.2
12	3.0	5.3	6.2	7.2	8.9	16.2	11.5	12.9	14.6	16.0	17.5	19.1	20.6	22.1	23.0	24.9	26.8	28.5
13	2.5	6.7	4.3	5.6	7.4	8.2	10.0	11.2	13.1	14.5	16.0	18.1	19.0	21.0	22.6	26.6	25.4	26.7
14	1.1	2.7	3.0	4.3	6.4	7.2	8.6	10.0	11.7	13.2	14.5	16.6	10.6	20.3	21.2	22.5	24.6	25.9
15	0.7	1.8	2.5	6.6	5.4	6.2	7.3	8.6	10.5	11.8	13.4	14.8	16.4	18.6	19.4	20.8	23.8	25.6

No XIX —Focus Skin Distance FS = 30 cm
Effect of Focus Skin Distance on Depth Dose

D_s / d	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%	42%	44%
1	70 4	71 8	76 0	77 1	77 4	77 7	78 1	78 0	81 7	82 4	83 2	83 0	84 0	85 5	86 0	86 8	87 0	87 4
2	56 2	61 0	62 1	62 6	64 2	65 0	65 8	66 8	67 8	68 8	69 7	70 0	71 0	72 7	73 4	74 5	75 8	76 7
3	48 0	49 4	50 5	51 8	52 3	53 5	53 8	54 9	56 3	57 4	58 0	59 7	61 0	62 1	63 2	64 4	65 8	66 8
4	38 2	40 2	41 4	42 7	43 0	44 1	45 2	46 5	48 0	49 3	50 5	52 1	53 1	54 3	55 0	56 1	58 0	60 1
5	30 0	32 4	34 0	35 2	36 0	37 1	38 2	39 5	41 1	41 5	44 0	42 2	43 6	45 0	46 4	49 2	52 0	53 0
6	24 5	26 2	27 6	28 0	30 2	31 4	32 7	34 2	35 8	36 3	36 7	38 0	39 5	41 0	42 3	43 7	46 7	48 0
7	18 0	21 4	22 4	24 0	24 8	26 8	27 0	29 4	31 1	32 5	34 0	35 0	37	38 7	40 2	41 0	43 0	44 8
8	15 6	16 5	18 1	19 8	20 7	22 4	24 2	25 7	27 6	28 0	30 0	31 0	33 0	35 2	36 8	38 0	40 8	42 2
9	11 1	10 0	14 3	16 0	17 2	18 9	20 7	22 2	24 0	25 6	27 1	28 7	30 3	31 0	33 4	34 0	36 6	38 1
10	8 1	9 7	11 4	12 0	14 0	16 1	17 6	19 3	21 1	22 7	24 3	25 6	27 0	29 2	30 8	32 8	34 0	35 6
11	5 0	7 0	9 6	10 2	12 2	13 6	15 1	16 8	18 6	20 0	21 6	22 5	24 2	25 6	27 6	29 1	32 1	33 5
12	4 0	6 6	6 0	8 1	10 0	11 4	12 6	14 4	16 3	17 0	19 6	21 4	23 1	24 7	26 4	27 9	30 0	31 0
13	2 8	4 2	4 0	6 3	8 3	9 2	11 1	12 6	14 7	16 3	18 0	20 3	22 1	21 7	25 4	26 0	28 5	30 1
14	1 2	3 0	3 5	4 9	7 2	8 1	9 7	11 3	13 2	14 0	16 3	18 7	21 4	22 6	24 6	25 3	27 7	29 2
15	0 8	2 1	2 8	4 7	6 1	7 0	8 2	9 8	11 0	16 4	15 2	16 8	18 6	20 4	22 0	23 5	26 8	28 8

No. XX.—Focus Skin Distance FS = 10 cm.
Effect of Focus Skin Distance on Depth Dose.

d \ D_x	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%	34%	36%	38%	40%	42%	44%
1	71.5	75.9	77.2	78.4	78.6	79.0	79.3	80.0	83.0	83.9	84.5	85.2	86.0	86.6	87.3	88.2	88.4	88.6
2	61.1	63.6	64.1	64.6	66.3	67.1	68.0	69.0	70.0	71.1	72.1	73.0	74.0	75.2	75.8	76.9	78.3	79.2
3	50.2	51.6	52.7	54.1	54.6	55.8	56.2	57.3	58.8	59.9	61.3	62.4	63.9	64.0	66.0	67.2	68.7	69.8
4	40.0	42.7	43.9	45.4	45.7	46.9	48.0	49.4	51.0	52.4	53.0	55.4	56.4	57.7	59.2	59.6	62.3	63.6
5	33.2	34.8	36.6	37.8	38.7	39.9	41.1	42.5	44.2	44.0	44.8	45.4	46.6	48.4	49.6	52.9	55.9	58.9
6	26.7	28.6	29.6	31.5	32.9	34.2	35.7	37.3	39.1	39.9	40.0	41.4	43.1	44.7	46.2	47.9	50.6	53.1
7	20.6	23.6	24.7	26.5	27.4	29.0	30.8	32.4	34.3	35.8	37.5	39.2	41.0	42.6	44.4	45.9	47.4	48.8
8	16.7	18.4	20.2	22.0	23.1	24.9	26.9	28.0	30.7	31.9	34.1	35.5	37.4	39.2	40.9	42.4	45.5	47.0
9	12.5	14.6	16.1	18.0	19.3	21.2	23.3	25.0	27.0	28.8	30.5	32.3	34.1	35.9	37.6	39.2	41.2	42.8
10	9.3	11.1	12.6	14.3	16.2	17.9	19.5	21.4	23.4	25.2	27.0	28.8	30.0	32.4	34.2	35.9	37.8	39.5
11	6.7	9.0	10.3	11.5	14.0	15.5	17.2	19.2	21.3	22.9	24.0	25.7	27.6	29.6	31.5	33.3	36.7	38.2
12	4.6	7.0	8.9	9.4	11.6	13.2	15.0	16.7	18.9	20.7	22.7	24.8	26.8	28.0	30.7	32.4	34.8	37.0
13	3.2	4.9	5.7	7.4	9.7	10.7	13.0	14.7	17.2	19.1	21.0	23.7	25.9	27.7	29.7	31.4	33.3	35.2
14	1.4	3.5	4.1	5.8	8.5	9.6	11.4	13.3	15.9	17.0	19.3	22.1	25.3	27.1	28.4	29.6	32.7	34.5
15	0.9	2.5	3.3	5.6	7.2	8.6	9.8	11.7	14.2	16.0	18.1	20.0	22.2	24.3	26.2	28.9	30.6	33.7

No. XXI.

Biological Doses (Holfelder).

20 to 25	per cent	U S D	produces	erythema	in an infant	2 to 3 months old
25 to 30	,,	,,	,,	,,	,, ,,	4 to 6 ,, ,,
30 to 35	,,	,,	,,	,,	,, ,,	7 to 12 ,, ,,
35 to 45	,,	,,	,,	,,	in a child	1 to 2 years old
50 to 60	,,	,,	,,	,,	,, ,,	2 to 3 ,, ,,
60 to 70	,,	,,	,,	,,	,, ,,	4 to 7 ,, ,,
70 to 80	,,	,,	,,	,,	,, ,,	7 to 10 ,, ,,
80 to 100	,,	,,	,,	,,	,, ,,	17 to 16 ,, ,,
100	,,	,,	,,	,,	in an adult	10 to 60 ,, ,,
110	,,	,,	,,	,,	,, ,,	60 to 70 ,, ,,
130	,,	,,	,,	,,	,, ,,	70 to 80 ,, ,,
70 to 80	,,	,,	,,	,,	in patients suffering from	exophthalmic goitre
60 to 80	,,	,,	,,	,,	,, ,, ,, ,,	psoriasis
60 to 90	,,	,,	,,	,,	,, ,, ,, ,,	eczema
80 to 90	,,	,,	,,	,,	in hypotonic cases	
60 to 90	,,	,,	,,	,,	in patients suffering from	diabetes

50 to 70	per cent	U S D,	produces	pigmentation
80	,, ,,	,,	,,	epilation
150 to 180	,, ,,	,,	,,	erythema bullosum
180	,, ,,	,,	,,	ulceration

34	per cent	U.S D	will	destroy	ovarian follicles
60 to 70	,, ,,	,,	,,	,,	sarcoma cells
90 to 110	,, ,,	,,	,,	,,	carcinoma cells
135	,, ,,	,,	,,	,,	intestinal tissue
180	,, ,,	,,	,,	,,	muscular tissue
50	,, ,,	,,	,,	,,	tubercular tissue
24	,, ,,	,,	,,	,,	the spleen

TABLES FOR PROTECTION

No. XXII.

Lead Protection Recommended for Various Tensions (British Protection Committee).

The following lead equivalents are recommended as adequate:—

X Rays Generated by Peak Voltages.	Minimum Equivalent Thickness of Lead
Not exceeding 75 K.V.	1 mm.
,, ,, 100 ,,	1 5 ,,
,, ,, 125 ,,	2 ,,
,, ,, 150 ,,	2 5 ,,
,, ,, 175 ,,	3 ,,
,, ,, 200 ,,	4 ,,
,, ,, 225 ,,	5 ,,

In the case of radiography, the operator should be afforded protection from scattered rays by a screen of a minimum lead equivalent of 1 mm.

No. XXIII.

The Lead Equivalent of Various Materials (Dr. G. W. C. Kaye).

After the major part of this book had gone to press, my attention was called to the following table, published in the *British Journal of Radiology* by Dr. Kaye, with whose permission it is reproduced here.

Architects and others who design radiological departments will derive considerable information as to the protective qualities of walls—notably in regard to concretes of various composition.

Material	Mean Density.	Lead Equivalent	Equivalent thickness of material in mm			
			50 K.V.	100 K.V.	150 K.V.	200 K.V.
	gm./c.c.	mm	mm	mm	mm	mm
Aluminium	2·7	1	96	60	65	70
		2	—	120	130	140
		3	—	180	195	210
Brass	8·4	1	6·5	1·5	6	6·5
		2	—	9	13·5	16
		3	—	14	21·5	27
		4	—	19	30	40
Steel	7·8	1	11·5	6·5	9·5	11·5
		2	—	15	21·5	25
		3	—	21·5	34	30
		4	—	32	47	53
Lead Glass	4·0 to 3·1	1	4 to 7·5			
		2	8 „ 15			
		3	12 „ 22·5			
		4	16 „ 30			
Lead Rubber	5·6 to 3·3	1	2 to 5			
		2	4 „ 10			
		3	6 „ 15			
		4	8 „ 20			
Barium Plaster 2 parts coarse $BaSO_4$, 2 „ fine „, 1 „ Portland cement	3·5	1	10	4	7·5	9
		2	—	9	18	25
		3	—	14·5	29	43
		4	—	20	41	65
Concrete 4 parts Stone chippings, 2 „ Sand, 1 „ Cement	2·1	1	100	70	75	80
		2	—	130	145	150
		3	—	190	215	220
Concrete 4 parts Clinker, 1 „ Cement	1·5	1	135	100	105	110
		2	—	200	210	220
Concrete 4 parts Granite, 1 „ Cement	2·1	1	110	70	80	85
		2	—	145	160	170
		3	—	215	240	260
Coke Breeze	1·2	1	200	110	—	130
		2	—	220	—	270
Daneshill Brick, red	1·9	1	125	100	110	120
		2	—	200	220	250
Stock Brick, yellow	1·5	1	170	130	150	170
		2	—	280	350	450